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GENERAL ELECTRIC REVIEW

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NOVEMBER, 1925



Magnification: 400 diameters

HOW THE MICROSCOPE PROTECTS INDUSTRY

Slag Inclusions in Alloy Steel. A Source of Weakness in Metals which the Microscopist can readily detect.
A Serial Article on this subject appears on p. 800.

In This Issue:

Oil Line Pumping

Liquid Dielectrics

Ultra-violet Therapy

Crushing Stone

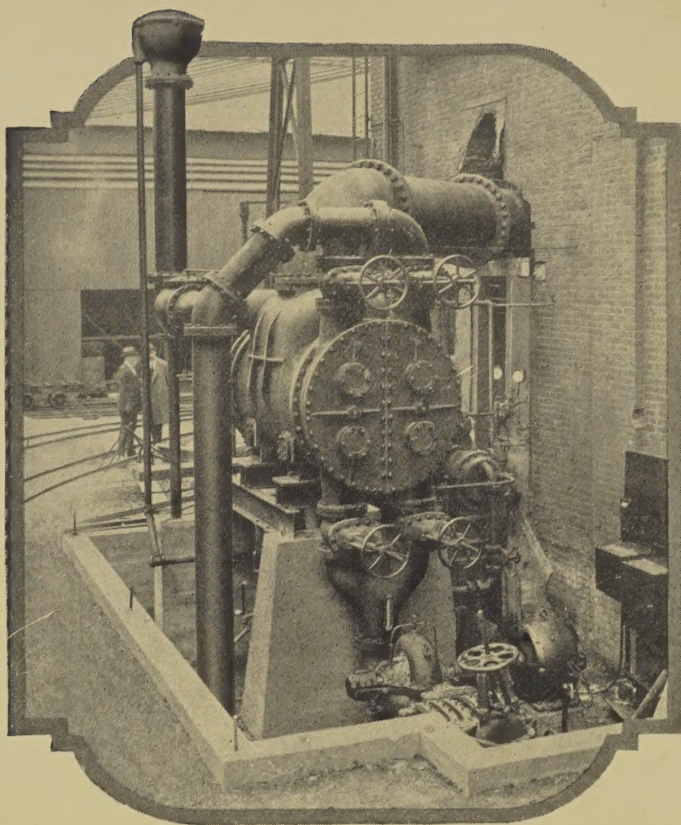
Dimensional Notation

A Power-factor Nomogram

Metals Through the Microscope

Computing Device for Transmission Lines

Testing Turbine-generator Output



High Vacuum for the Industrial Power Plant

Condensing equipment for a 500-kw. turbine in an industrial plant.

THE small plant can also profit from high vacuum. The Wheeler Surface condenser with centrifugal circulating and hotwell pumps and steam jet air pump forms the simplest and most reliable condensing apparatus. The centrifugal auxiliaries require far less steam than reciprocating pumps and are practically trouble proof. The steam jet air pump is simple, economical and produces a high vacuum.

The condensate from the surface condenser forms pure boiler feed water.

The vacuum produced by this outfit is limited only by cooling water conditions.

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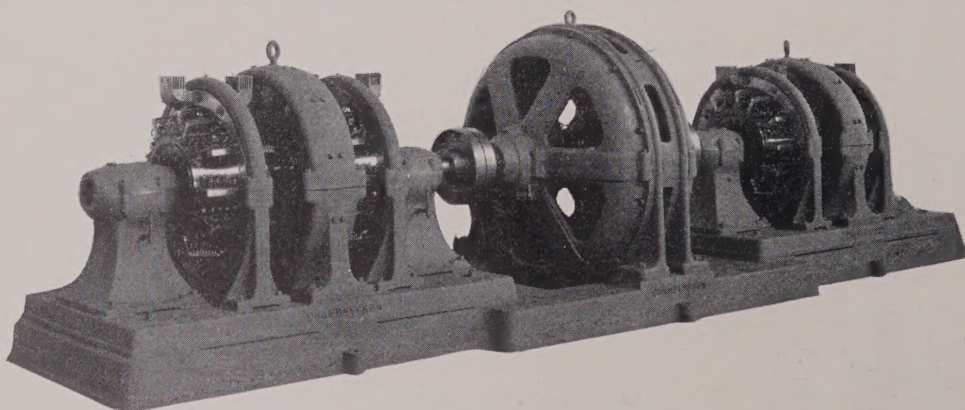
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Types T-B-P
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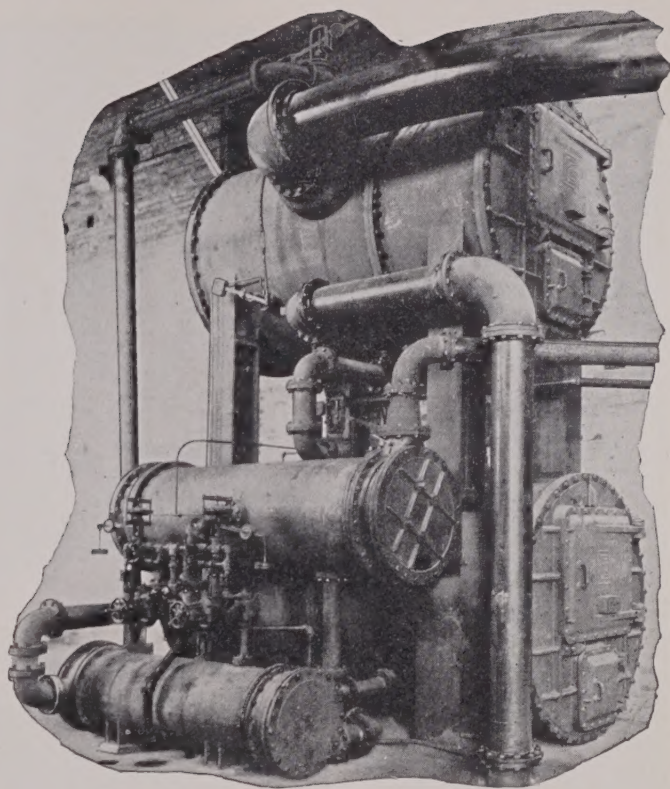
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Industrial Plants realize the need for Deaeration

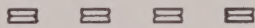


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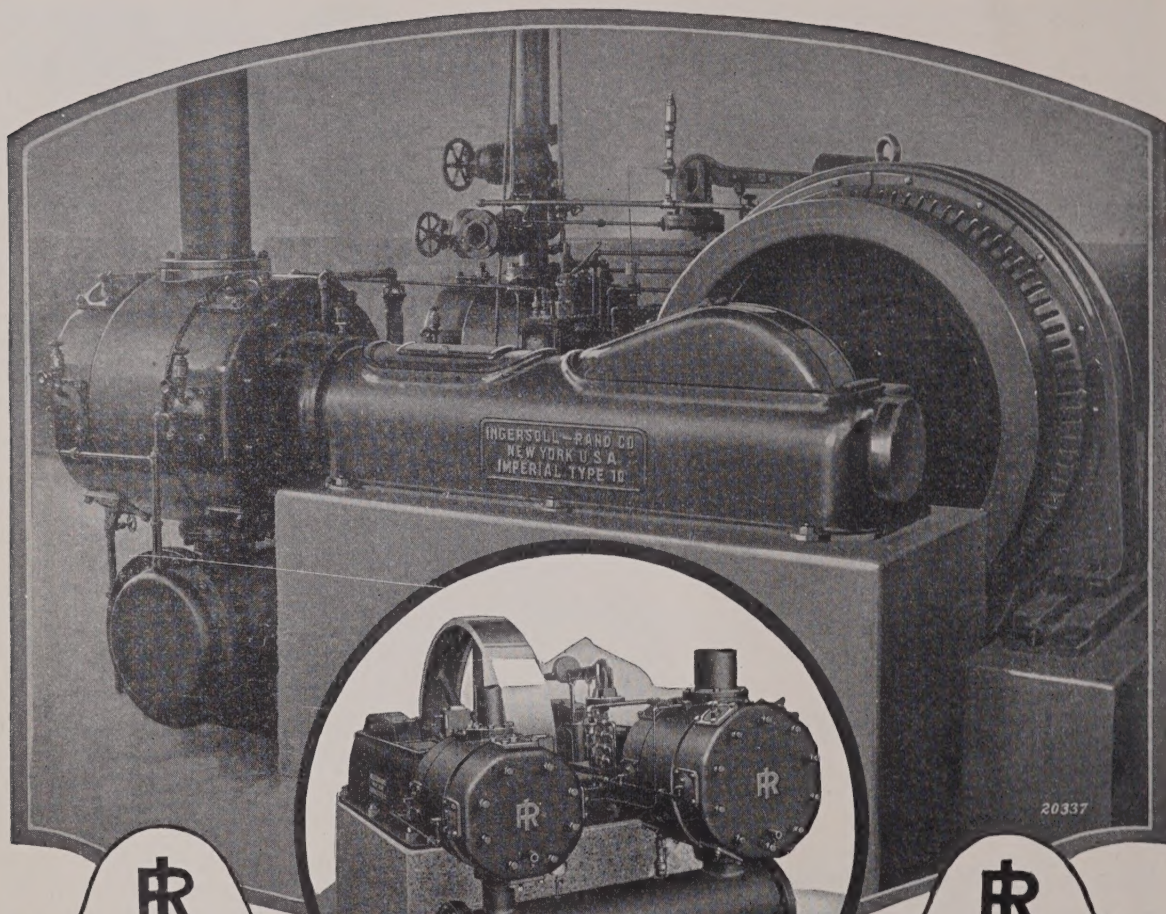


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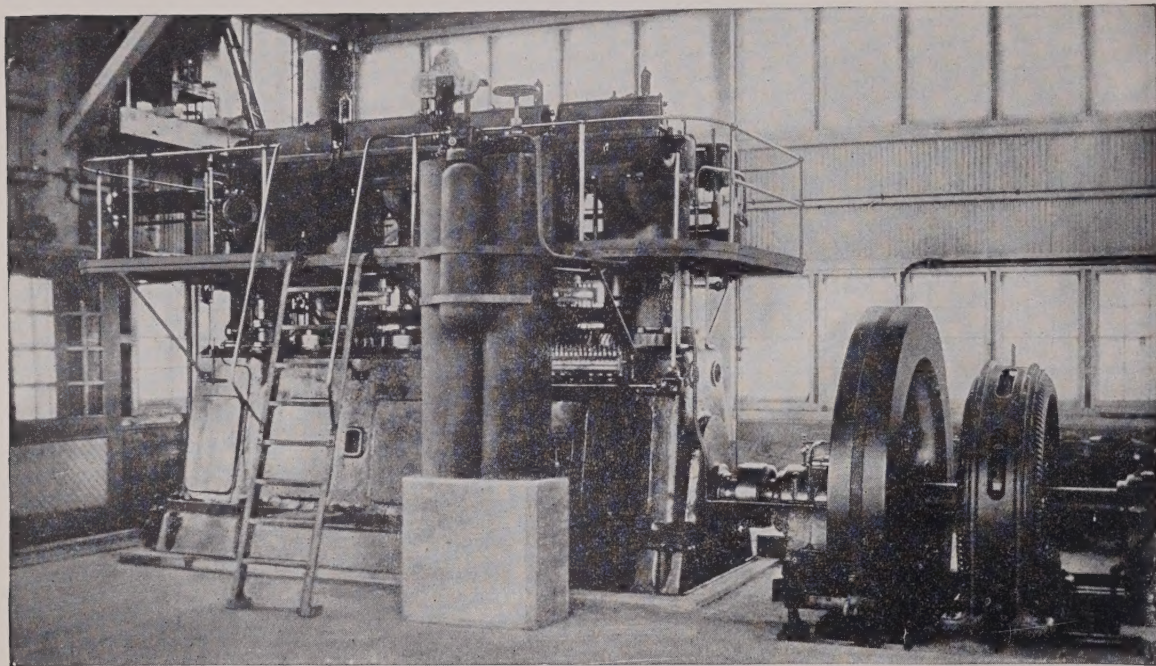
Be sure to attend this great Exposition and send one or more

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NOVEMBER 30th to DECEMBER 5th



A typical small Diesel-electric power plant complete. No large buildings, boilers, chimney, power-consuming auxiliaries, big pipe lines, coal and ash-handling equipment, etc., and no dust, smoke, noise or mess. Requires from $\frac{1}{6}$ to $\frac{1}{8}$ as much fuel as a steam-electric plant and only one man to operate.

\$20,000 Saved in Fuel during the first year's operation

THE Phillips County Electric Light & Power Company, Phillipsburg, Kansas, replaced their steam-electric plant with a 600-b.h.p. McIntosh & Seymour Diesel Engine and 400-kw. generator. This Diesel-electric outfit went into service on March 31, 1923. During the first month the load was very light, ranging from 40 kw. after midnight to about 200 kw. during the peak periods. A total of only 64,000 kw. hr. was generated. Even at this light load factor of about 22 per cent. the Diesel engine effected a fuel saving of \$800 over the steam plant, in spite of the fact that some fuel

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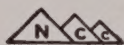
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Emergency Service Plants

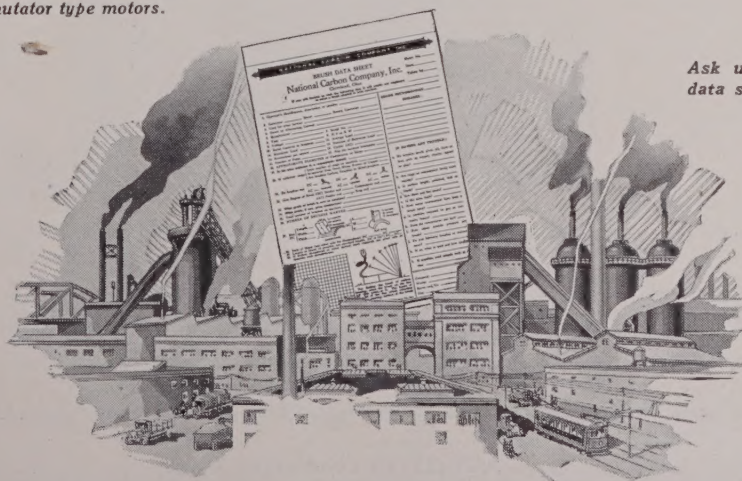
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NEW YORK OFFICE—100 BROADWAY

BIRMINGHAM OFFICE—AMERICAN TRUST BUILDING

Low Head

High Speed

High Efficiency

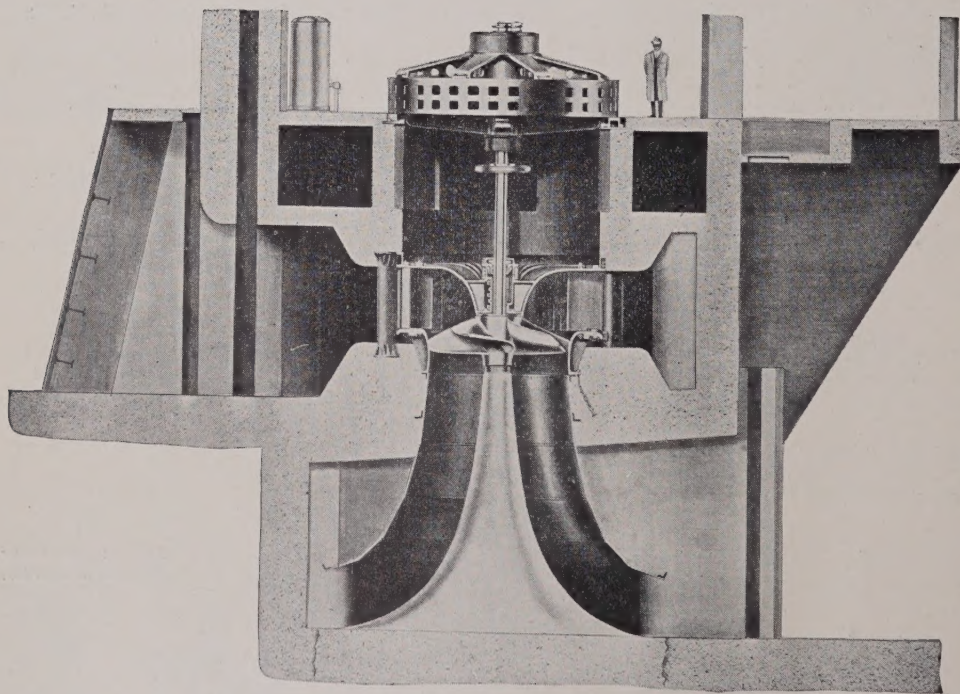
Turbines built for
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SPECIAL FEATURES

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Moody Diagonal-Flow High-Speed Runners

Individual Stay Vanes and Plate Steel Guide Vanes



5—1500 Horsepower Turbines Operating at 120 R.P.M. Under a Normal Head of 15.5 Feet

Units of this type equipped with HIGH-SPEED RUNNERS and HIGH CONE SPREADING DRAFT TUBES give HIGH EFFICIENCIES with this simple and inexpensive setting and make possible the development of low-head power sites which were previously considered uneconomical.

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These Men are Working for You

No better Ball Bearing is made anywhere on earth than a New Departure.

No manufactured product is more insistently and persistently inspected for the slightest defect, than a New Departure Ball Bearing.

These inspections might be classified under three headings:—Basic or analysis of raw material, Process or manufacturing, and Final or quality.

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Every one of these inspections is an assurance of fulfillment on the part of this Company of its aim to produce the quality ball bearing of the world.

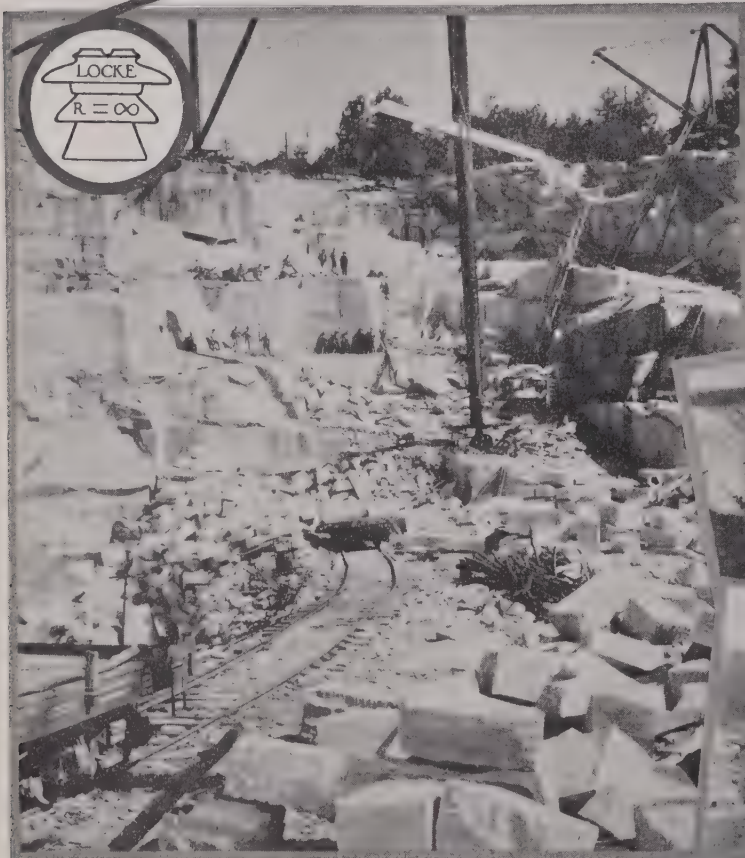
THE NEW DEPARTURE MANUFACTURING COMPANY
Detroit, Mich.

BRISTOL, CONNECTICUT

Chicago

262

At Home in the Granite Industry



Are you from Vermont—or have you visited this beautiful Green Mountain State? If so, you will thrill to the feeling of this native tribute:—

"Up where the north winds blow just a little keener,
Up where the grasses grow just a little greener,
Up where the mountain peaks rise a little higher,
Up where the human kind draws a little nigher,
That's where Vermont comes in.

Up where the snows of winter last a little longer,
Up where the heart beats just a little stronger,
Up where the hand-clasp is just a little warmer,
That's where Vermont comes in.

Up where the lonesome pine its nightly requiem sighs,
Up where the unpolluted waters take their rise,
Up where the sons of toil have fought for freedom's sod,
Up where all nature's mood is a little nearer God.
That's where Vermont comes in."



BARRE, VERMONT, GRANITE is the best quality of monumental granite quarried in the world. This important industry is served with electric energy from two native sources of power—the Montpelier and Barre Light and Power Company, with its county-wide system of seventeen generating and sub-stations; and the Burlington Light and Power Company's "Little Niagara" at Essex Junction.

Locke Porcelain, from which the insulators are made which carry the power lines of these two systems, is much at home in the granite industry, for Locke Porcelain is in reality a synthetic granite, fused from the same basic minerals which constitute original granite—the imperishable "Rock-of-Ages." Locke Insulators, made from Locke Porcelain, are everywhere carrying the power lines of American Industry.

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Export Agents: International General Elec. Co., Schenectady, N. Y.

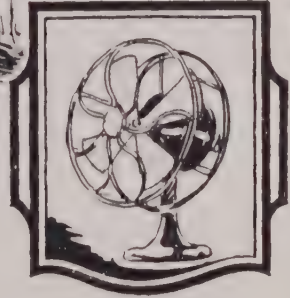
LOCKE

PORCELAIN

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*from locomotive to fan
the right brush for every
need*



And while there is a vast difference between a Stackpole Carbon Brush on a locomotive and on an electric fan, yet they both have a common characteristic—uniformity in composition.

The exceptionally long life of Stackpole Brushes and their efficient functioning under all stresses will make you a permanent user.

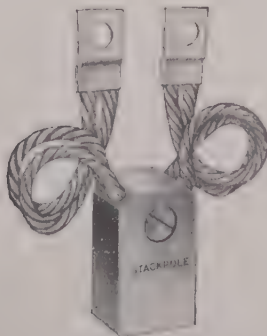
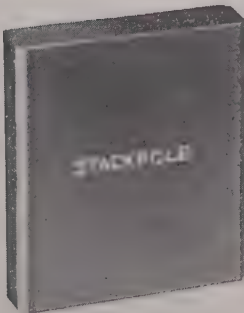
Chattering, high mica, heating, flat spots — Stackpole Carbon Brushes eliminate them all.

Let us send our
Catalog No. 8

Stackpole Carbon
Company

St. Marys, Penna.

***Stackpole
carbon brushes***



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PRECISION ROLLER BEARINGS

Make
Good
Motors
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PRECISION BALL, ROLLER AND THRUST BEARINGS

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"INDIANA"

Double Galvanized Telephone and Telegraph Wire

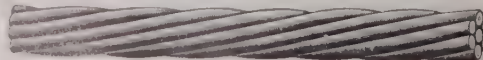
CRAPO PATENTS

Non-Peeling—Non-Cracking

At last the Telephone and Electrical Industry is assured longer life and lower maintenance on galvanized wire construction through our *new* and *improved* patented Galvanizing Process, which insures a wire with Non-Peeling and Non-Cracking Zinc Coating. Now in full commercial production. Carried in stock by Representative *Supply Jobbers*.

Illustration at right shows what happens to old process galvanizing, while the illustration at left shows assured results of CRAPO PROCESS—(patented)

Galvanized Steel Strand

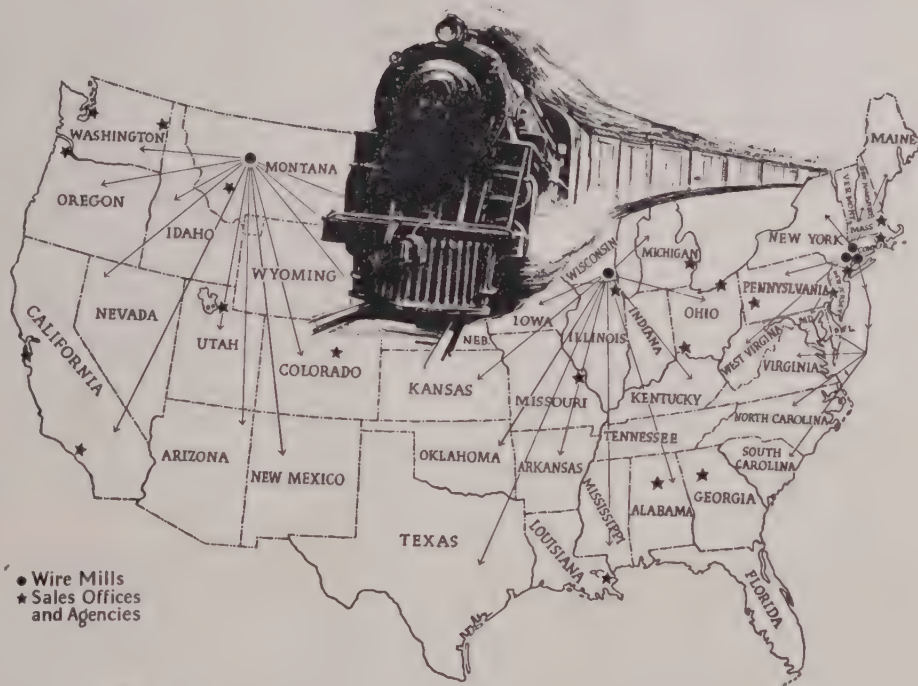


Standard or Commercial, Siemens-Martin, High Strength
and Extra High Strength Grades

Indiana Steel & Wire Company, - - Muncie, Indiana

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5 Wire Mills *at your service*



The new Anaconda Wire Mill at Kenosha, Wis., rounds out Anaconda's unequalled facilities for nation-wide service on Copper Wire.

Anaconda Copper Wire Products include Bare, Weatherproof and Slow Burning Wire and Cable. Paper Insulated, Lead Sheathed and Varnished Cambric, Insulated Lead Sheathed or Braid Covered Power Cable, Copper and Hitenso Trolley Wire.

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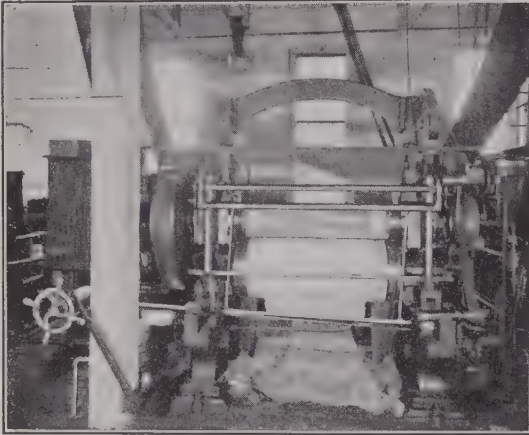
General Sales Offices: 25 Broadway, New York
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Keystone Safety Lubricator applying grease to the bearings of a textile calender from a central point.

And on these machines—

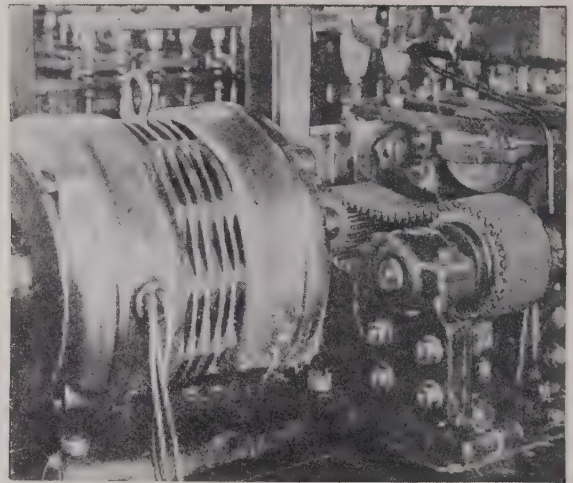
Records show, after careful checking, that the investment made in installing the Keystone Safety System of Keystone Grease Lubrication on the following machines, was returned within six months to a year.

Mosser Grinder Rolls (Cement)
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Calenders (Textile)
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Dumping Kettles (Linoleum)
Lap Weld Finishing Mill
Cranes
Butterworth Dryers
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Shurtle Stuff Pump
Mine Locomotives
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Shears (Metal)
Charcoal Elevator
Fire Engine Pump
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Rag Cutter
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Mill Motor

Keystone Lubricating Co., 21st and Clearfield Sts., Philadelphia, Pa. Established 1884. Branch Offices and Warehouses in the principal cities of the world



MORSE SILENT CHAIN DRIVES



15 H.P. Morse Silent Chain Drive from motor to spinning frames. Driver, 1170 r.p.m.; driven, 865 r.p.m.; 10-inch centers.

Speed Reduction Plus

There are many ways of transmitting power and providing a desired speed ratio between driving and driven shaft, but Morse Silent Chains with original rocker joint have never been excelled for:

Sustained efficiency—98.6%
Positive speed ratio
Quiet operation at all speeds
Convenience of application
Reliability, long life, low upkeep

Morse Silent Chains to the extent of over 4,000,000 h.p. ranging from $\frac{1}{4}$ to 5000 h.p. have been installed. Speeds from 6000 to 250 r.p.m. or slower. Particularly effective on short centers.

Write for "A Chain of Evidence" or consult Morse engineer at nearest office.

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654

The triple-guaranteed expansion joint



GUARANTEED

[1] To compress one quarter inch axially when subject to a compressive force of 125 pounds per inch nominal diameter of pipe.

[2] To expand one quarter inch axially when subject to an expansive force of 150 pounds per inch nominal diameter of pipe.

[3] To distort laterally one eighth inch with a force of 125 pounds per inch nominal diameter of pipe.

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the
Coupon



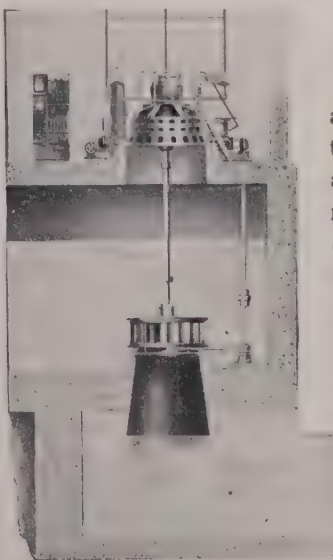
THE GRISCOM-RUSSELL COMPANY

2140 West St. Building, New York

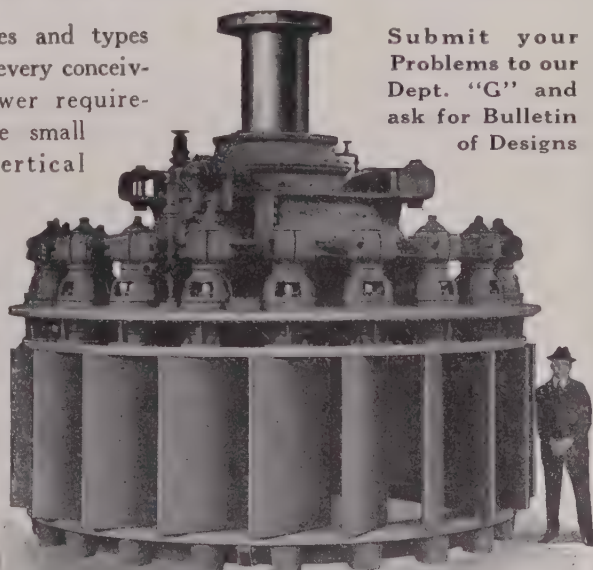
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Address.....
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Gentlemen: Please send us a copy of Informa-
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GER 10-25

SMITH HYDRAULIC TURBINES



are built in sizes and types to meet almost every conceivable water power requirement from the small open flume vertical shaft unit as shown on the left, to the huge turbines of 20,000 to 30,000 h.p. each, as shown on the right.



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Problems to our
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ask for Bulletin
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There's 50 years' experience, and Plant Equipment second to none, back of SMITH TURBINES.

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Motors

Due to their low temperature rise and heavy overload capacity B.T.H. Motors give reliable service under the most arduous conditions. They are manufactured in all sizes over a wide speed range and can be supplied for either alternating or direct current systems.

The design of these motors is based on extensive experience of industrial drives of every description, and thus they are of extremely robust construction and give continuous service with minimum attention.

To assist in giving full information of the most suitable type of motor kindly indicate the duty to be fulfilled.

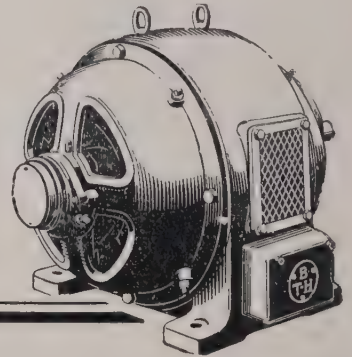
The British Thomson-Houston Co., Ltd

Electrical Engineers and Manufacturers

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Manager, M. P. RICE

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NOVEMBER, 1925

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The Shell Company of California Replaces Its Steam-engine-driven, Reciprocating-pump, Oil-line Station at Signal Hill with an Electrically-driven, Centrifugal-pump Station for the Same Volume and Pressure. The abandoned steam plant in the rear occupies 55 by 100 ft. and is only three or four years old; the electric plant in the foreground requires a space of but 17 by 37 ft. and cost less than one-quarter as much as the other. (See page 752)

GENERAL ELECTRIC REVIEW

MASTER OF ALL TRADES AND JACK OF NONE

Last month we took occasion on this page to refer to electricity as the magic workman who can be molded to fit perfectly into his surroundings. If when hired his physical characteristics—as alternating current, direct current, voltage, frequency, and number of phases—do not conform to the situation ideally, they can easily be made to do so by rectification, inversion, transformation, or conversion.

We might also have added that, while he is readily responsive to these alterations called for by certain factors of environment, many other factors which impose a limit on the performance of the human workman, and indeed other agencies of work, present no bar to his operation. From absolute zero to the temperature of the sun he displays the same active characteristics. To his movement, uphill and downhill are alike. He has no surface, therefore cannot be subjected to the crushing effect of mechanical pressure, and when sent into a vacuum he just radiates activity.

On the other hand, the human worker can carry on his operations only amid surroundings that have a comparatively small range of temperature, and to preserve his very existence he must avoid regions of heavy pressure or a vacuum. The capacity of falling water to do work ceases when an obstruction prevents it from longer following the course of gravity. Coal in a vacuum can produce no heat. Steam at very low temperature becomes non-existent. Fuel oils at such temperatures are too viscous to be serviceable. And to attempt to put a combustible gas to work in a vacuum is absurd.

Then there is another group of characteristics which electricity displays. Though all of these are not always essential, they make the worker who exhibits them much to be

preferred in any situation. We refer to tireless performance, directly and simply rendered without introducing moisture or dirt, quantities of waste heat, objectionable odors or danger of asphyxiation, and done also with the minimum noise and fire hazard.

Having noted some of the features relating to the foregoing workmen and their surroundings, let us turn to some of the features that exist in connection with these workers and the objects for which they are employed. The work calls for the delivery of light, heat, or power. Unaided, man can produce no light, can liberate heat in no useful quantity, and by his utmost exertion can deliver only an insignificant amount of power. Falling water can directly produce only power; solid fuels like coal are limited to the direct furnishing of heat only; steam delivers power as well as heat, but not light; and though some of the oils and combustible gases can directly produce all three, this combination in utility is not extensively made of any of them. On the other hand, electricity is employed to deliver energy in all these forms with equal facility.

Though so versatile, this worker is not independent of those who in the foregoing we have considered as his brothers for some of them are also his father, others his grandfather, and most of his operations are carried on with one or more of them as his sires. Our moral is that they can accomplish more as his sires than as his brothers.

As brothers, they are decidedly his inferior with respect to the economy and convenience with which they can be brought to our widely distributed places of varied activity. And when there, none of them can compare with this master workman who needs only the proper tools with which to do whatever job he is assigned.

E. C. S.

The Instant Heavisidion—A Kinematic Computing Device for Long Transmission Lines

By VLADIMIR KARAPETOFF

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A few years ago Professor Karapetoff developed a computing device for the solution of transmission line problems to which device he gave the name "Heavisidion." The instrument was composed of numerous adjustable links and scales with which any setting for line constants could be made. This original Heavisidion required considerable precision in workmanship in order to exclude errors due to lost motion. Professor Karapetoff now comes forward with the Instant Heavisidion, which is a modification of the original—not so universal in its adjustments, but much easier to build, and requiring no previous practice to operate. In this article he explains the device, its theory, and practical use.—EDITOR.

Introduction

Among the problems with which a power transmission engineer is concerned, is that of finding the current, the voltage, and the phase angle at one end of a long transmission line when the same quantities at the other end are known. The quantitative relationships among these quantities are quite involved, because of the distributed capacitance of the line, and are expressed by either hyperbolic or exponential functions of a complex variable. Thus, straightforward analytical computations are rather tedious because so far no one has been able to develop a practical computing device, of the nature of the slide rule, for use with complex quantities. For this reason, various shortcut methods have been proposed, analytical, graphical, or involving alignment charts and scales, linkages, etc.⁽¹⁾

The purpose of the present device (Figs. 1 and 2) is to enable the current, the voltage, and the power-factor at one end of a long line with given distributed constants to be determined, by simply reading three scales, when the corresponding quantities at the other end of the line have been properly set by means of three other scales. Thus, the principal fields for the use of the device should be (a) after the size of the conductor and the spacing have been definitely settled, for the solution of a projected line, and (b) in the case of an existing line, to predict the operating characteristics, the required size of synchronous condensers, etc., under some proposed new conditions.

The device has been named the "Heavisidion" in honor of Oliver Heaviside, who was among the first to establish and to solve the funda-

mental differential equations of a long line with uniformly distributed resistance, inductance, capacitance, and leakance. The first Heavisidion built⁽²⁾ had adjustments for changing the line constants, and moreover it enabled the current-voltage relations to be determined at any point on the line, and not only at the ends. Having set the linkages for one end of the line, it was necessary to roll two sharp-edged wheels in opposite directions until the setting at the other end of the line had been reached. In other words, the first Heavisidion was not instantaneous in its action. Moreover, because of adjustable linkages, the device had to be made by a precision mechanician and required expert handling.

Experience has shown a need of a much simpler device, without any adjustments, made expressly for a particular transmission line, and a device which would indicate the current-voltage relations at the intermediate points. To distinguish this device from the preceding one, based on the same mathematical principle, the new device has been named the "Instant Heavisidion." It will be seen from Fig. 1 that it mainly consists of a few celluloid bars drilled at the ends and assembled by means of small bolts or rivets. Such a device can be readily made by anyone with very limited shop facilities. Should it be desired to change the line constants or the length of the line, it is just as easy to drill a few new holes and to assemble the device anew, as to try to adjust a universal one.

Notation

In Fig. 3, the "primed" quantities and letters refer to the generator end and the unprimed quantities to the receiver end of the line. The diagram is the same as in Fig. 7 of the paper on the original Heavisidion,⁽²⁾ so that only the results will be

(1) Of the latter, the Transmission Line Calculator, developed by Miss Edith Clarke, has proved to be quite useful in the design and study of operating characteristics of long transmission lines. See GENERAL ELECTRIC REVIEW, June, 1923, Vol. XXVI, p. 380.

(2) A. I. E. E. Trans., 1923, Vol. 42, p. 42.

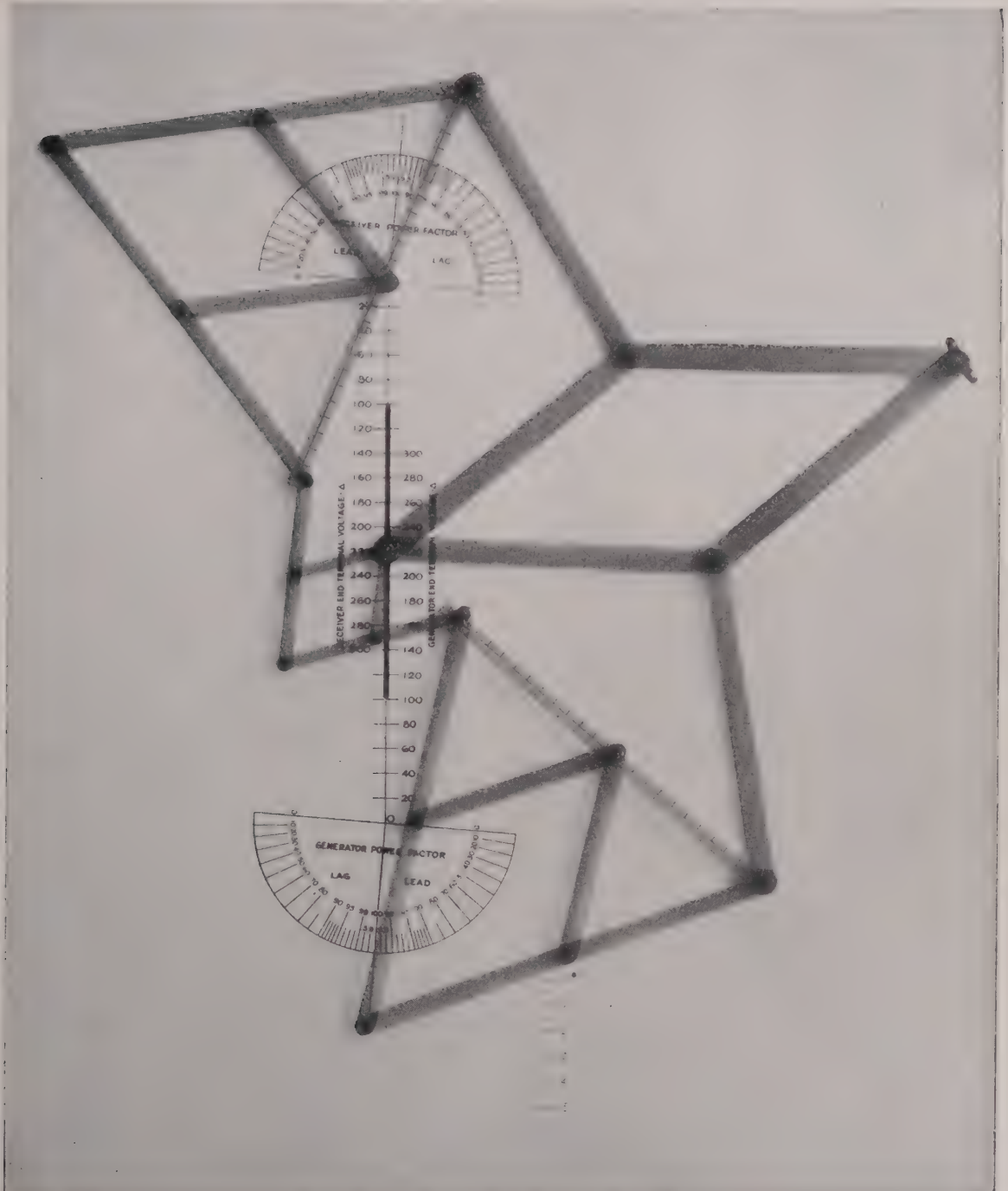


Fig. 1. The Instant Heavisidion for Transmission Line Calculations

The device is here shown set for receiving end conditions, 218 volts, 245 amp., 95 per cent lagging power-factor. By manipulating the instrument along the slot and about the central pivot, generator end conditions can be read directly from the lower scales. (The vertical scale beneath the lower link of the Heavisidion is in centimeters and is included in the photograph merely to indicate the mechanical dimensions of the device.)

given here, without a proof. $OC=E$ is the receiver voltage, per phase of Y of a three-phase line, and I is the corresponding current at the receiving end of the line, per phase, lagging behind E by an angle ϕ .

Let the line be defined by the following constants, per phase, per unit length:

- r resistance, in ohms per mile
- x reactance, in ohms per mile
- g leakance, in ohms per mile
- b capacitive susceptance, in ohms per mile

With a given size and material of the conductor and a given spacing, values of r , x and b may be obtained from available tables or curves. We furthermore introduce the resistance angle θ_r , defined by the expression

$$\tan \theta_r = \frac{r}{x} \quad (1)$$

and the leakage angle θ_g , defined by

$$\tan \theta_g = \frac{g}{b} \quad (2)$$

The following auxiliary quantities will also be needed:

Line impedance (series) per unit length, in ohms:

$$z = \sqrt{x^2 + r^2} \quad (3)$$

Line admittance (shunted) per unit length, in ohms:

$$y = \sqrt{b^2 + g^2} \quad (4)$$

Surge or natural impedance of the line:

$$z_s = \sqrt{\frac{z}{y}} \quad (5)$$

Differential angle of the line:

$$\theta = 0.5 (\theta_r - \theta_g) \quad (6)$$

Imperfection angle of the line:

$$\tau = 0.5 (\theta_r + \theta_g) \quad (7)$$

Attenuation constant of the line, a numeric per unit length:

$$\alpha = \sqrt{zy} \sin \tau \quad (8)$$

Wavelength constant of the line, in radians per unit length

$$\beta = \sqrt{zy} \cos \tau \quad (9)$$

V-ratio of the line (a numeric)

$$v = e^{\alpha l} \quad (10)$$

where e is the base of natural logarithms and l is the length of the line. The ratio v is best computed from the equation

$$\log_{10} v = \frac{\alpha l}{2.3} \quad (11)$$

V-turning angle, in degrees,

$$\gamma = 57.3 \beta l \quad (12)$$

In Fig. 3, the vector $OD = z_s I$ is drawn at an angle $-\theta$ to I , that is, lagging if θ is positive. CA and CB are equal and parallel to OD . The points A and B determine the auxiliary voltages $OA = V_a$ and $OB = V_b$. The Heavisidion is based on some simple properties of the vectors V_a and V_b , as explained in the following paragraphs.

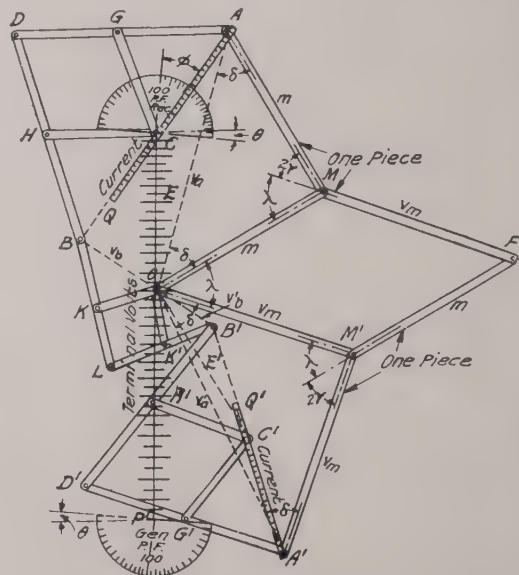


Fig. 2. Schematic Diagram of the Heavisidion with Vector Quantities and Angular Displacements Shown

Theory

In Fig. 3, let the triangle OAB , together with its median line OC , represent the conditions at the receiver end. OC is the phase voltage and CA is the current measured on the voltage scale. To get the current in amperes, CA in volts must be divided by z_s . The phase angle

$$\phi = \angle OCB - \theta \quad (13)$$

The corresponding triangle for the generator end is $OA'B'$ and its median line, OC' , represents the generator voltage in its true magnitude and phase position. The new triangle is determined by the auxiliary voltage vectors $OA' = V_a'$ and $OB' = V_b'$, which are obtained from V_a and V_b in the following simple manner:

To obtain V_a' , turn V_a counter-clockwise by the angle γ and multiply it by v . To obtain V_b' , turn V_b clockwise by the angle γ and divide by v . These propositions follow directly from equations (4) and (5) in the

A.I.E.E. paper⁽²⁾. To obtain the generator current, it is only necessary to divide $C'B'$ (in volts) by z_s . The phase angle

$$\phi' = \angle OC'B' - \theta \quad (14)$$

The purpose of the Heavisidion is to provide kinematic linkages which automatically change OA into OA' and OB into OB' , for any desired initial values of current, voltage, and power-factor.

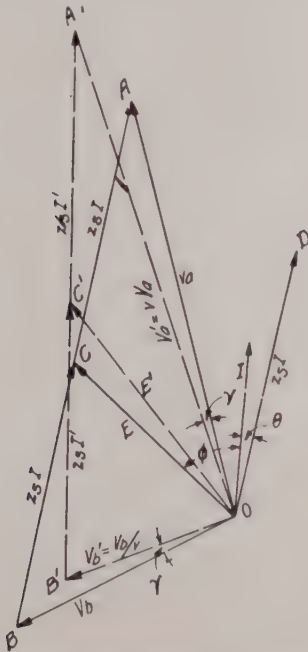


Fig. 3. Elementary Diagram of Transmission Line Conditions Upon Which the Instrument is Based. Generator end quantities superimposed on receiver end quantities

The relative positions of the generator and receiver-end triangles, as actually used in the device, are shown in Fig. 4. The same triangles, for somewhat different data, are shown by dotted lines in Fig. 2, the lettering being the same throughout. It will be seen that in these figures the generator-end triangle has been turned with respect to its true position by an angle equal to $180 \text{ deg.} + \gamma$. This is done in order to cause the vectors V_b and V_b' to lie on the same straight line and thus to simplify the mechanical linkages. The angle between V_a and V_a' is increased by the same amount and becomes equal to $180 \text{ deg.} + 2\gamma$.

Construction

The variable voltage and current vectors are realized in the device by means of the

three pairs of proportional dividers shown in Figs. 1 and 2. The one-to-one ratio dividers ADB fix the center point C for any given positions of A and B . Similarly, the dividers $A'D'B'$ determine the center point C' for any given positions of A' and B' . The proportional dividers BLB' are so made that the ratio of OB to OB' is equal to v . Consequently, for any value of V_b they give the

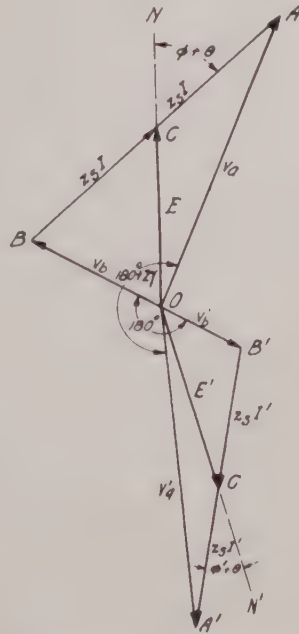


Fig. 4. The Next Step in Adapting the Vector Diagram to the Actual Heavisidion Construction. One set of vectors has been reversed without altering their geometric relations

correct magnitude of V_b' and its phase position according to Fig. 4.

In order to establish and to preserve the angle $180 \text{ deg.} + 2\gamma$ between V_a and V_a' (Fig. 4), the linkage $AMFM'A'$ is provided. The bent bar AMF consists of the arm AM of some suitable length m , and of the arm MF of the length vm . The meaning of v has been explained in the paragraph on Notation. The angle between the two arms is equal to 2γ . The bent bar $A'M'F$ has two arms of the same lengths, m and vm , only the longer arm is next to A' . The angle at M' is also equal to 2γ . A screw with a wing-nut is provided at F . The points M and M' are connected to O by the links $OM = m$ and $OM' = vm$. This gives two isosceles triangles, AMO and $A'M'O$ and a parallelogram $OMFM'$. The two triangles

always remain similar to each other because the angles M and M' remain equal to each other no matter how the parallelogram may be deformed. Hence the ratio of OA' to OA always remains equal to v . From the triangle AMO we may write

$$2\delta + 2\gamma + \lambda = 180 \text{ deg.} \quad (15)$$

But

$$\angle AOA' = 2\delta + \lambda \quad (16)$$

Comparing equations (15) and (16) we see that

$$\angle AOA' = 180 \text{ deg.} - 2\gamma \quad (17)$$

which agrees with the value shown in Fig. 4 and also proves the correctness of the linkage $MF M'$.

Instead of laying off or reading the angles $ACN = \phi + \theta$ and $A'C'N' = \phi' + \theta$ (Fig. 4), and correcting for θ , the two protractors in Figs. 1 and 2 are shown tipped at an angle θ to the center line CP' . In this manner, the correction for θ is taken care of automatically and one can read the phase angles ϕ and ϕ' directly. In addition to these angles, or in their stead, the protractors may be graduated directly in values of $\cos \phi$, or power-factor. Such divisions are shown in Figs. 1 and 2. The protractors may either be drawn on the piece of paper which serves as a base for the device, or laid out on separate pieces and temporarily attached to the baseboard.

A slot is provided along the center line CP' , and a vertical pin whose center line passes through O fits snugly in this slot and can be moved along it. Two voltage scales are shown in Fig. 1 along CP' , one for receiver-end volts, the other for generator-end volts. The zero points of these scales (points C and P') are arbitrary and should preferably be chosen with reference to the best operating range of the linkages (least lost motion). To avoid multiplying the results by $\sqrt{3}$, to change from the Y-voltage to the terminal voltage, the scales may be graduated directly to read the latter voltages. Theoretically, the scales AQ and $A'Q'$ should be calibrated to read to the same scale as Y-voltages. To obtain a current in amperes, the readings should be divided by z_s . In practice, this factor can be taken into account in the scale itself, and the divisions marked directly in amperes. The reading edge of the scale AQ should be along the center line AB . The same applies to $A'Q'$.

In some cases it is preferable to read both volts and amperes in centimeters and

to multiply the readings later by the proper factors. This does away with the necessity of making awkward odd scales, which usually are not so accurate as standard engraved millimeter divisions.

The proportional dividers and the other bars of the device are preferably made of celluloid or of a similar material, such for example as is used for draftsmen's triangles. The holes at the ends of the bars should be accurately drilled to give the desired lengths between the centers. Small brass bolts with nuts, or rivets, can be used for pivot joints. The fit should be quite tight to avoid lost motion. The "layers" should be carefully considered. Some bars will rest directly on the baseboard and constitute the first layer; others will be on top of these. The assembly should move freely, without binding or interference.

The size of the device is not limited by any particular dimension. The lengths of the bars of the particular device shown in Fig. 1 may be estimated from the centimeter scale in the lower part of the illustration. A smaller device may be more convenient for use on one's desk, while a larger device will be more accurate and is suitable for a separate table or a drafting board.

The proportional dividers ADB and $A'D'B'$ have no parts which depend upon the line constants, and therefore may be used for any line. The dividers BLB' must divide the

length BB' at O in the ratio of $\frac{v}{1}$. This ratio is different for different lines. By providing a number of holes in the four bars which constitute this pair of dividers, the ratio may be changed in small steps within the practical range. The two parts of the bar AMF may be fastened to each other in an adjustable manner, so that the angle between them can be made of a desired magnitude. By drilling several holes, the lengths vm may also be made adjustable for a given value of v . With such and other small additions the device can be made to represent transmission lines of different lengths and with different constants.

Setting and Use

We shall assume the quantities E , I , ϕ , at the receiver end to be given (Fig. 2), and those at the generator end E' , I' , ϕ' , to be desired. The wing-nut at F should be released.

(a) Set $I = AC$ on the current scale AQ .

- (b) Turn the proportional dividers $A D B$ until the desired value of ϕ (or $\cos \phi$) is read on the upper protractor, along the edge of AQ . Note: The point of intersection of the two short links GC and HC must fall at the center, C , of the protractor.
- (c) Holding the points A and B fixed, move the pivot O along the slot until the proper value of E is reached. The lower portion of the device is now automatically set for the quantities at the generator end.
- (d) Read the generator current on the scale.
- (e) Clamp the wing-nut at F (to preserve the setting) and rotate the entire device about O , at the same time sliding O in the slot until the point C' coincides with P' . The generator voltage is then read off at O and the power-factor on the lower protractor, at the point determined by the scale $A'Q'$.

Of course, the receiver quantities are not always the known quantities. When the values at the generator end are given, the procedure is the same, beginning with the lower half of the Heavisidion. Generally speaking, the device is a linkage with three degrees of freedom. When three conditions

have been imposed upon its parts, the setting becomes definite and the three remaining quantities may be measured.

Actual experience shows that with careful handling the accuracy of the results is fully equal to that obtained by the analytical method with hyperbolic functions of a complex variable. Of course, when only one result is required, the building of a device would be hardly warranted. But where the same line is to be studied under different conditions of load and voltage, an Instant Heavisidion will save considerable time with much lesser probability of errors. Moreover, it does not require a skilled operator, nor one familiar with higher mathematics. It is simply a transmission-line slide rule, its only limitation being that (without adjustable parts) its use is confined to a line of particular chosen constants.

The author wishes to express his appreciation to Mr. R. E. Doherty, Consulting Engineer of the General Electric Company, for encouraging the development of the Instant Heavisidion and for providing the necessary means and facilities. The first experimental Instant Heavisidion, shown in Fig. 1, was built by Mr. K. C. Mobarry, at the time a member of Mr. Doherty's staff. To him the author is under obligation for his interest in the device and his painstaking workmanship.



A Long Sweep of High-voltage Transmission Line Whose Operating Characteristics Can Easily be Determined on the Instant Heavisidion

Evolution in Oil Line Pumping Equipment

By WILLIAM N. BEADLE

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The author of this paper gives us an interesting study in contrasts—of steam-driven reciprocating pumps versus electrically-operated centrifugal pumps in the oil pipe line service in California. Low cost of maintenance, reduction of pipe line resistance, simplicity of control and reduction of fire hazard are some of the points favoring electric drive as a result of actual operating experience.—EDITOR.

Introduction

One of the most important steps in the production of petroleum is the movement of the crude oil from the wells to the refinery. While oil wells are located in diverse sections of the country, it is found most economical to establish the refining plants at central points, usually on tidewater, and to transfer the oil to them by means of pipe lines and pumping plants. In the past the practice has been to use steam-driven reciprocating pumps to move the oil, but there is a growing tendency today to replace these with less cumbersome and more efficient electric-driven centrifugal pumps. The present article will outline some of the advantages of the more modern method and demonstrate, from actual examples in the California oil fields, its claim to superiority.

A Comparison

A striking comparison of steam-reciprocating pumps and electrically-driven centrifugal pumps is furnished in Fig. 1. The larger building houses the steam pumps and boilers. It covers a space of 55 by 100 ft. and represents a total investment of over \$80,000. The small building in the foreground contains two motor-driven centrifugal pumps whose capacity and discharge pressure are equal to the pumps in the large building, yet the cost of this installation, including the building values and piping, was only \$18,000 and it occupies a piece of ground 17 by 37 ft.

Furthermore, the labor cost in operating the steam plant is several times greater than that of running the motor-driven plant where only one man per shift is required. Both units in Fig. 3 can be transported on an ordinary large motor truck whereas several trips were necessary to move one of the steam pumps to the location. Each of the electrically-driven pumps consists of a 5-in., 4-stage compound Byron Jackson Multiplex Centrifugal Oil Line Pump direct connected to a 200-h.p. General Electric motor built for

operation on 3-phase, 50-cycle current at 2200 volts.

The California Petroleum Corp. Installation

The first important installation of motor-driven centrifugal oil pumps in California, and probably the first in the world, was composed of six 200-h.p. units operated by the California Petroleum Corporation in the vicinity of Los Angeles. These units were put in operation in September, 1923, and up to April, 1925, had handled 20,000,000 barrels of oil, with total repairs during that period of less than \$200. These pumps will handle the entire 36,000,000 barrels of oil contracted for by the Standard Oil Company of New Jersey, to be delivered over a three-year period.

This pioneer installation of electric centrifugal pumps for pipe line service is the culmination of efforts to overcome the prejudice in favor of reciprocating pumps, which have been used exclusively on oil pipe lines for high pressures. The difficulty encountered in the introduction of new types of equipment lies in overcoming this conservatism on the part of old oil men and their preference for time-tried products. Credit is, therefore, due to Mr. I. W. Fuqua, president of the California Petroleum Corporation, for deciding in favor of centrifugal pumps to fulfill the Standard Oil contract.

The company's pipe line system extends from Signal Hill, at Long Beach, California, through Willow Street Station to the tank farm at Watson, a distance of approximately five miles, and from Watson to the company's marine loading station at Los Angeles harbor.

Under the old method of pipe line power installation a large reciprocating steam pump with boilers, steam lines, etc., would have to be operated at the Signal Hill end of the line to pump oil to the Watson tank farm. A second group of reciprocating pumps and steam equipment would also be required at Watson to carry the oil to the harbor.



Fig. 1. A Contrast in the Size of Two Types of Pumping Plant of Equal Capacity: the building in the background houses steam-driven reciprocating pumps, and the one in the foreground contains motor-driven centrifugal pumps

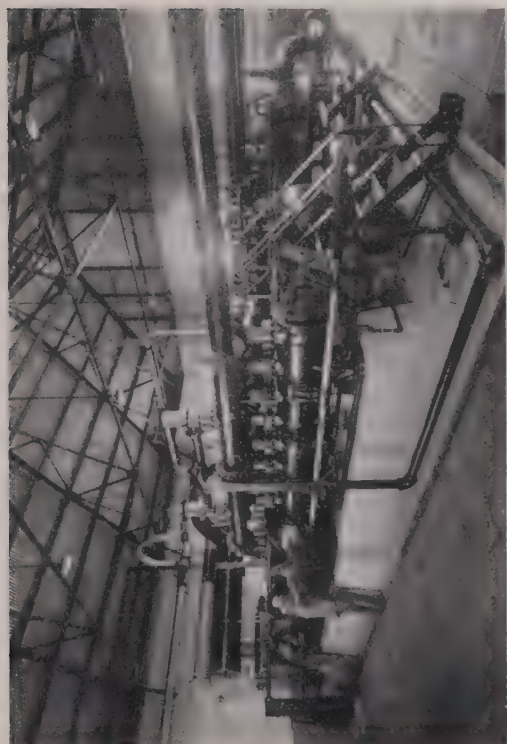


Fig. 2. Interior View of the Steam Plant Shown in Fig. 1

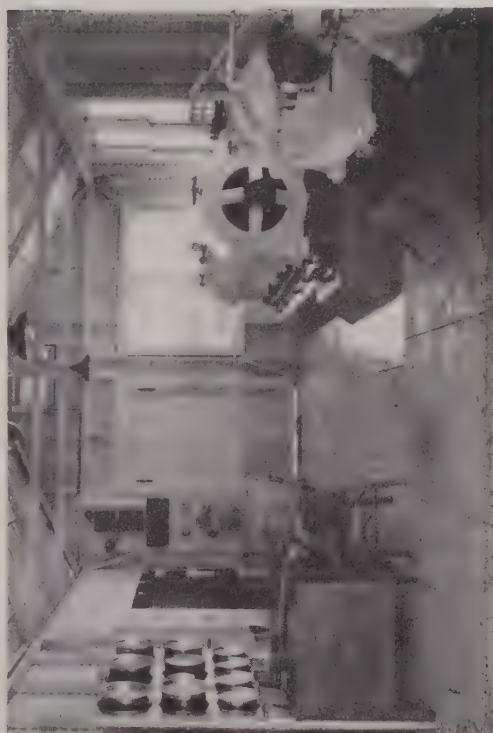


Fig. 3. Simple and Compact Arrangement of Pumps in the Electrically-driven Plant Shown in Fig. 1



Fig. 4. Another Electrically-driven Centrifugal Pumping Station

The electric centrifugal pump installation for this system includes the following:

At the Signal Hill station, one 200-h.p. centrifugal pump direct-connected to an electric motor, controlled by a hand starter

At Willowville, midway between Signal Hill and Watsonville, one 200-h.p. automatically-operated electric pump, connected directly to the oil line without storage tank

At Watsonville, four 200-h.p. pumps, one of which is used as an auxiliary pump.

on the 10-in. line at this point. Tests show that the two units operating "in parallel" pump 2833 barrels of oil per hour, or 68,000 barrels per day, against a discharge pressure of 260 to 300 lb. Two pumps in series are used to deliver 14 to 16 deg. Baumé gravity residuum fuel oil to Los Angeles Harbor at 600 to 650 lb. pressure at the rate of 34,000 barrels per day.

The performance of the pumps exceeded the guarantees in the initial test run, when delivering into four 80,000-gallon storage tanks at the Marine Loading Station.

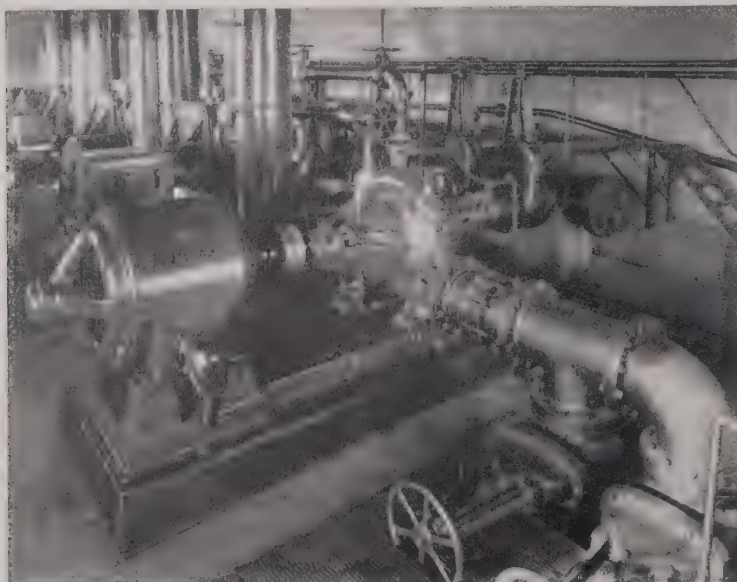


Fig. 5. A 100-h.p. Motor Driving a Centrifugal Pump for Oil Loading at Los Angeles Harbor

All of this equipment is electrically driven, a feature which has resulted in exceptional economy, requiring a minimum of space and attention.

Automatic Operation

A special feature of this installation is the automatically operated unit at the Willowville station. This pump is equipped with a pressure regulator which automatically starts the pump as pressure is built up by Pump No. 1 at Signal Hill, and similarly shuts it down when the pressure drops due to stopping Pump No. 1.

At present the oil is being pumped from tanks at the Watson farm to Los Angeles Harbor by the two 200-h.p. pumps installed

Efficiency and Economy

The centrifugal pump is more adaptable to electric drive than is the plunger type of pump, as it is necessary to transmit power to the reciprocating type by means of gears and shafts or gears and chain drives, which are expensive both as to initial cost and maintenance. With the centrifugal pump a direct-connected electric motor affords not only the most efficient power transmission, but has also a considerably lower first cost and a maintenance which is practically negligible.

Centrifugal pumps maintain an even flow through the line since the impulse given to the oil is continuous. Due to their uniform delivery pressure, the pipe line resistance as measured by various investigators is con-

siderably smaller than when the same rate of delivery is maintained by a reciprocating pump. The instantaneous delivery rate of a plunger pump fluctuates to some extent, depending on the number and size of the cylinders, and even with a large air chamber for "cushioning" at the discharge, the capacity curve of the triplex, and more markedly, of the duplex pump, will be of a wave shape. This irregularity in the delivery rate means that the oil in the whole line, being incompressible, must be accelerated and decelerated with each impulse, thereby causing an increase in the effective pipe-line resistance.

Another serious drawback to the plunger type of pump is the fact that it cannot be

line, assuming that there is 50 lb. to spare after overcoming the line drop between the two, the second unit will deliver the oil at 350 lb. into the second section of the line. Thus the power cost represented by the 50 lb. excess pressure is fully conserved, and not wasted as would be the case if the oil were discharged into a tank and then picked up again by the second pump at atmospheric pressure. Such an arrangement is employed on the Signal Hill-Los Angeles Harbor line of the California Petroleum Corporation.

Another important advantage in using electric-driven centrifugal pumps is the ease with which absolute control of the discharge can be maintained by gate valves at the delivery end of the line. When the storage tank or oil steamer at the loading dock is filled, the gate valve at the discharge point can be entirely closed, cutting off the flow of oil without any hazard to the line. The centrifugal pump is so constructed that there is considerable clearance between the blades of the impeller and the housing, and when the discharge is closed, the pump will build up a certain "static" pressure, after which it will cease to function as a pump, merely churning the oil, and holding a constant pressure on the discharge valve. This action of the centrifugal pump was demonstrated a short time ago, when the gate valve on a line $17\frac{1}{2}$ miles long, with a 300-h.p. centrifugal gasoline pump, normally delivering at 700 lb. pressure, was closed. The spectators were inclined to seek places of safety, but everything remained intact, and after building up a static pressure of about 1000 lb. the pump continued to churn the fluid in the housing with no further increase in pressure, and with no damage to itself or to the line.

Design

The six California Petroleum Corporation pumps are each 5-in., 4-stage, bronze-fitted "Multiplex" units, and are mounted on ruggedly constructed cast-iron bases, on extensions of which are placed the 200-h.p. electric motors which furnish the power. The motor and pump shafts are direct-connected with a flexible coupling of the rubber pin-buffer type between. All gears, countershafts and chain drives are thus avoided. The overall dimensions of a unit are 15 ft. by 4 ft., and two complete units can be loaded on an ordinary auto truck.

By reference to Fig. 3 it will be seen that both suction and discharge connections are on the same side of the pump. This permits



Fig. 6. Automatic Electric Centrifugal Pump Installation for Boosting Oil Line Pressure

used directly in a pipe line as a pressure "booster." Were this to be attempted, and the various pumps along the line not accurately synchronized, "kicking" or "bucking" would result between units, and no fixed pumping pressure could be maintained. Therefore, the use of reciprocating equipment necessitates the maintaining of an exceptionally high pressure at the beginning of the line, to overcome the resistance between stations. At the end of the pipe section there must be a delivery tank and another pump to deliver the oil into the next section. Such "tank stations" represent a considerable investment in tank equipment and real estate. With the centrifugal type of equipment, any number of installations can be made directly on the pipe line without the use of tanks, and each succeeding pump will utilize whatever pressure is maintained over the line drop by the preceding unit. To illustrate, if 300 lb. pressure is built up at the starting point of an oil line and a second centrifugal pumping unit, also designed for 300 lb. pressure, is installed at the center of the

the oil suction line from the field tanks and the oil discharge line to be located on one side of the pump house, and makes the "hook-up" of necessary valves, etc., much more convenient, and their installation less expensive. The opposite side of the unit being free of all piping, permits the use of a smaller pump house and gives the set a neat appearance.

The pump case proper houses the rotating impellers, four in number, which are made of bronze and mounted back to back, thus eliminating all tendency to develop thrust on the shaft. That is, two of the impellers have their suction openings facing one way, while the other two face in the opposite direction. The impeller shaft is of high-grade steel, and is protected by a special metal sleeve where it passes through the pump case or packing gland or comes in contact with the liquid being pumped. The cases are split horizontally on the center line, which permits easy removal and inspection of the interior, or the lifting out complete of the impeller and shaft if necessary. The rotating parts can be removed without disturbing either discharge or suction connections.

These pumps are being manufactured up to and including discharge pressures of 1000 lb. per sq. in. A unit of this design has been operating for one of the large oil companies since 1923 with a normal discharge pressure of 700 lb. and a static pressure of 1000 lb.

Fire Hazard

Virtually complete protection against the ignition of the oil being pumped, by arcs in the electrical apparatus, can be secured by the construction of an inexpensive fire wall around the motors, with a suitably designed packing gland in the wall around the motor shaft. Such a wall will effectively "blank off" the motors from the pumps. It must be built of solid concrete projecting high enough around the motor to prevent any oil from getting near enough to the electrical apparatus to be ignited by an arc.

However, with modern squirrel-cage induction motors there is no electrical connection between stator and rotor, and the power leads are all solidly connected, so that arcs are not likely to occur. The starting compensators are arranged to make and break contact in oil, thus protecting this operation

against contact with inflammable material. With all the wiring in heavy conduit, the fire risk is at a minimum; in fact, it is considerably less than with the fires that must be used under the boilers in a steam pumping plant. This was strikingly demonstrated by an explosion in a steam plant caused by the boiler fires, which resulted in the death of two men and the wrecking of the plant.

In case of an emergency in which an oil line breaks, or there is a serious leak of oil from some cause, a switch placed remote from the pump house can be used to stop the motor.

Conclusion

In view of the fact that the electrically-driven centrifugal pump can accomplish the movement of oil in pipe lines far more smoothly and safely than the reciprocating pump, it is to be expected that this type will come into rapidly increasing use. A reciprocating plant, with its high investment in machinery and real estate, its greater maintenance and operating charges, and its lesser degree of convenience and safety should give way to the more compact, less expensive, and more efficient centrifugal pumping station. Due to the fact that such pumps operate on a 24-hr. schedule, it is possible to secure very favorable power rates by offering a high load factor. Ease of control permits a station to be operated on one-man shifts throughout the day.

At the present time there is a network of oil pipe lines, most of them fitted with steam pumping units, extending in a great semi-circle from Texas and the Gulf of Mexico northward and eastward via the Great Lakes to New York. Oil fields are being developed in New Mexico and adjacent territory. California is at present the foremost oil-producing state. A pipe line from Los Angeles to tide-water in Texas would complete the system and provide for the free movement of oil either eastward or westward. Thus it would be of tremendous value in meeting market conditions, accommodating new production centers in years to come, and insuring a ready continuity of supply in time of war.

With this favorable entrance of electrically-powered centrifugal pumps in the California pipe line system, extensive avenues for future development are opened.

Dimensional System of Notation

By V. PETROVSKY

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The inability of the mathematician's numerical method of calculating to cope with the various fundamental units introduced in engineering calculations has been the subject of much discussion by physicists, engineers and mathematicians. Many systems of notation have been devised in an effort to make the correct application of formulas a certainty. In this article the author presents a modification of older attempts at dimensional notation.—EDITOR.

When a mathematician uses the term *quantity*, he usually means a numerical quantity, simple or complex. Nothing prevents him from performing any mathematical operation with his quantity. He may sum it up with its square, he may take its logarithm, he may use it as an exponent. Now, the quantities which an engineer uses are physical, i.e., dimensional quantities, and not numerical. A physical quantity of a certain magnitude is a definite quantity but is not a number at all. Physical quantities can be operated algebraically but only as far as the results can be interpreted physically. This imposes some limitations non-existing in the mathematics of abstract numbers. For example, if a is a certain amount of length, expressions like $a+a^2$, $\log a$, e^a , have no meaning.

The system of notation which is being used universally at the present time, and which may be called the numerical system, is a device intended to substitute numbers for quantities, chiefly in order to conform to the habits of mathematicians. The purpose is achieved by establishing the "systems of units." It is true that the ratio of a definite quantity to the corresponding unit quantity is an abstract number. Therefore, the numbers appearing in formulas and equations, expressed in the numerical system, are presumably abstract numbers. However, we are told that some of these numbers "represent" length in inches, others—time in seconds, etc. Thus, apparently, these numbers are not so abstract as the mathematician would like to see them but are slightly contaminated by their material origin. Then, there appear also "numerical factors," supposedly the purest numbers of all, because they are even explicitly called numerical. And still we learn that these factors depend on the "choice of units." It is clear that the system is not strictly mathematical. A more serious inconvenience arises from the fact that the formulas and equations presented in this system are not complete in themselves. Certain conventions are to be remembered, and these conventions

are different in different cases. It happens occasionally that no use can be made of a good formula, simply because we cannot find out whether that diameter is supposed to be "in inches" or "in feet," etc. It is unnecessary to give examples of difficulties often encountered in the use of formulas presented in the numerical system; every engineer has had his own experience with them. If the beautiful dreams of the fathers of the metric system, absolute system, etc., were realized, we should be living now in a kind of scientific paradise with one universal system of units for all. Under such conditions there would be no doubt in any particular case what units should be used, and the numerical system of notation, although not strictly scientific, would be at least working satisfactorily. Actually, after a century and more, we are still asking: "Is this formula in metric units or in English?"—"Are these small calories or large calories?" etc. Thus, the promised blessings did not come down to us; instead, we have inherited the conversion of units.

All difficulties can be eliminated by the use of the dimensional system of notation in which the physical quantities are consistently treated algebraically. And any work carried through in the dimensional system is readily understood by all those who ordinarily prefer to use the numerical system.

The Dimensional System

Physical quantities, such as weight, magnetic permeability, length, temperature, time, etc., are measurable properties of existing things. The physical *nature* of a quantity is distinguished by experience. The relations by which the magnitudes of various quantities may be interconnected are determined by physical laws. In many cases they can be expressed mathematically as equations or formulas, in which the quantities enter as magnitudes.

A quantity is called indefinite when its magnitude is of no concern, and its physical nature alone is considered. A quantity of a

certain magnitude, known or unknown, constant or variable, is called a definite quantity. Two definite quantities of the same nature can be added together, and the result is a definite quantity still of the same nature. If two quantities of different natures are added together, the result is a complex quantity, which may or may not have a physical meaning. There are cases of a more subtle distinction between quantities of the same dimensional nature, when they refuse to combine in a summation, and give, instead, a complex quantity. Familiar examples are: work and force-moment; surface tension and the strength of an elastic connection. This distinction is somewhat analogous to the geometrical difference in direction, and need not be considered in the present article. Excepting complex quantities, no new dimensional nature can arise from summation, and this is the reason why in the formulas expressing the inter-connection of different quantities, these quantities always enter as factors. The factors may have exponents, integral or fractional, positive or negative. According to the structure of the formula, the dimensional "nature" of the resulting quantity can be expressed symbolically as the product of the natures of the quantities involved. For example, the nature of length $[l]$ can be expressed as $[a^{1/2}]$ or as $[a q]$, where $[a]$ is the nature of area and $[q]$ is the nature of curvature. The nature of electric current $[i]$ can be expressed as $[f^{1/2} \mu^{-1/2}]$, where $[f]$ is the nature of mechanical force and $[\mu]$ is the nature of magnetic permeability. The nature of rate of interest $[r]$ can be expressed as $[s t^{-1}]$, where $[s]$ is the nature of money value and $[t]$ is the nature of time.

The dimensional nature of a physical quantity can be represented by various combinations of other quantities; the choice is merely a matter of convenience. *There are no quantities which are more fundamental than others.* The symbols representing the dimensional nature are created and changed according to necessity and convenience. Any standardization of symbols would be detrimental to the flexibility of the system.

Numerical, i.e., non-dimensional quantities, can also be included among the physical quantities. However, since a numerical factor does not affect the dimensional nature of a quantity, there is no need of a symbol for the nature of number. A simple test to determine whether a quantity is dimensional or not consists in adding to it a numerical quantity. If the result cannot be interpreted,

the quantity is dimensional, although the nature of it may not be expressible in terms of other known quantities. For example, if s is an amount of money value, the expression $s+4$ has no meaning; therefore, s is a dimensional quantity. Similarly, entropy, temperature, magnetic permeability, are not numbers, notwithstanding common opinion.

Operation of Dimensional System

In the dimensional system any number appearing in a formula or in an equation is always understood as an abstract number, never representing any physical quantity, and its magnitude cannot in any way be affected by the methods used for specifying the magnitudes of the physical quantities involved. On the other hand, any dimensional quantity appearing in an equation or in a formula has a magnitude which is not a number at all. Dimensional quantities are always expressed by the use of symbols. *No physical quantity can ever be represented by a number alone.* It is true that in order to specify the magnitude of a quantity a comparison must be made of the quantity with a known standard amount of the same physical nature, and it is true that the result of such a comparison is a number. However, this number is not the magnitude of the quantity but a ratio of two magnitudes. In the numerical system this ratio alone is written, and the basis of the comparison is supposed to be remembered. In the dimensional system the quantity is specified by writing this ratio, multiplied by the standard amount used. The writing is longer, but an absolute consistency and the absence of any ambiguity are attained. No "units" are prescribed. *There are no units in the dimensional system.* All the old unit quantities are among the standard amounts. For example, an inch of length is not a unity but is a certain known amount of length, a standard amount. A definite quantity is not specified "numerically" but is specified "in magnitude." This distinction is of considerable importance for the clear understanding of the dimensional system. Any convenient standard amount can be used, and can be changed freely, even during the course of the same problem. The only requirement is that a standard amount must be sufficiently definite, so that it can be recognized. The ratios between commonly used standard amounts are given in the ordinary conversion tables. Table I in this article is a conversion table showing the various standard amounts of power in use.

Any single-letter symbol, any arbitrary symbol or any abbreviation of the name can be used to represent the standard amount. These symbols are consistently treated as any algebraic quantities. For example, if the length of the room be designated by L_1 and the length of the desk by L_2 , and if it is known that the length of the room is four times the length of the desk, this fact can be expressed by the relation $L_1/L_2=4$. Here L_1 is an algebraic symbol representing the length of the room, i.e., a definite quantity of the nature of length $[l]$ but *absolutely without any numerical meaning*. The relation is correct, no matter what standard amounts are used to specify the magnitudes of L_1 and L_2 . If $L_1=18 \cdot \text{ft.}$ and $L_2=137.2 \cdot \text{cm.}$,

$$\frac{L_1}{L_2} = \frac{18 \cdot \text{ft.}}{137.2 \cdot \text{cm.}} = 0.1314 \cdot \frac{\text{ft.}}{\text{cm.}}$$

magnitudes of the quantities involved. If $H=100 \cdot \text{met.}$ and $\gamma=62.5 \cdot \text{lb. ft.}^{-3}$,

$$P = 100 \cdot \text{met.} \cdot \frac{62.5 \cdot \text{lb.}}{\text{ft.}^3} = 6250 \cdot \frac{\text{met.}}{\text{ft.}} \cdot \frac{\text{lb.}}{\text{ft.}^2}$$

From conversion tables, $\text{met.}/\text{ft.}=3.281$; therefore,

$$P = 6250 \cdot 3.281 \cdot \frac{\text{lb.}}{\text{ft.}^2} = 20,520 \cdot \frac{\text{lb.}}{\text{ft.}^2}$$

No numerical constants like mechanical equivalent of heat, etc., are needed. If $Q=W$, where Q is a certain amount of heat and W is a certain amount of work, Q and W are not numbers but two quantities of the same nature, which happen to be equal. Either of them can be expressed as a multiple of any desired standard amount of energy.

True numerical constants may appear in physical formulas which are derived by

TABLE I: Ratio $q_1:q_2$
Power $[f l t^{-1}]$. $[f]$ force. $[l]$ length. $[t]$ time.

$q_2 \backslash q_1$						
	B.t.u. hr.	Watt.	Lb.ft. sec.	Kg. met. sec.	H.P.	Kw.
B.t.u. hr.	1.	3.412	4.626	33.46	2545.	3412.
Watt.	0.2931	1.	1.356	9.81	746.	1000.
Lb.ft. sec.	0.2161	0.7373	1.	7.233	550.	737.3
Kg. met. sec.	0.02989	0.10194	0.1383	1.	76.04	101.94
H.P.	0.393×10^{-3}	1.340×10^{-3}	1.818×10^{-3}	0.01315	1.	1.341
Kw.	0.293×10^{-3}	10^{-3}	1.356×10^{-3}	0.00981	0.746	1.

From conversion tables, $\text{ft.}/\text{cm.}=30.48$; therefore,

$$L_1/L_2=0.1314 \times 30.48=4.$$

The length of the room can be expressed as $L_1=18 \cdot \text{ft.}$ or, if desired, as $L_1=4 \cdot L_2$. In the first case, the standard amount is ft. , in the second case, the standard amount is L_2 . The algebraic factor ft. in the first form cannot be omitted, just as the algebraic factor L_2 cannot be omitted in the second form. It is not permissible to write $L_1=18$, just as it is not permissible to write $L_1=4$. In long columns the repetition of symbols is avoided by giving the values of ratios; e.g., $L_1/\text{ft.}=18$.

As another example, the pressure of a liquid can be expressed as $P=H\gamma$, where H is the height of the column of the liquid and γ is the specific weight of the liquid. The relation expresses a physical law, and connects not numbers but the magnitudes of quantities P , H and γ . Therefore it must be independent of any methods used in measuring the

integration, although there are no numerical constants in the ultimate differential relations. For example, an elementary area in a circle, $da=r d\phi dr$, from which the integrated area of the circle, $a=0.7854 d^2$. Here the factor 0.7854 is a true numerical constant which cannot be affected by any methods of measuring diameters and areas. As another example, the elementary magnetic field intensity at point P , due to an element of current i , of length dl , is according to Laplace's Law (a differential relation),

$$dH = \frac{i dl}{r^2} \times \sin (dl, r)$$

where r is the distance between dl and P . By integration, the total magnetic field intensity at point P , due to an infinitely long straight current, is

$$H = 2 \frac{i}{h}$$

where h is the distance between point P and the current. Here the factor 2 is a true

numerical constant which cannot be eliminated by any choice of standard amounts.

Empirical formulas presented in the numerical system are always accompanied by a list of "units" to be used. If this list is absent, the formula is useless. If some other units have to be used, a tedious process of conversion is necessary. It will be shown how, by an algebraic transformation, any empirical formula presented in the numerical system can be reduced to a dimensional form which does not require any additional explanations and is entirely independent of any system of units. For example, the rotational loss of a disc rotating in steam is given by the formula:

$$L = 0.19 \left[\frac{W}{100} \right]^3 D^2 \gamma$$

with the explanation that W is a *number* representing the peripheral speed measured in ft. per sec., D = the disc diameter measured in ft., γ = the specific weight of the steam measured in pounds per cubic ft. and that the result is the *number* of kw. lost. In the dimensional system the number W of the formula is replaced by $W / (\text{ft. sec.}^{-1})$, which is also a number, but where W is *not* a *number at all* but a certain *amount* of velocity. Similarly, D is replaced by $D / \text{ft.}$, γ by $\gamma / (\text{lb. ft.}^{-3})$ and L by $L / \text{kw.}$ Then, the formula becomes

$$L = 0.19 \cdot \left[\frac{W \cdot \text{sec.}}{100 \cdot \text{ft.}} \right]^3 \cdot \left[\frac{D}{\text{ft.}} \right]^2 \cdot \frac{\gamma \cdot \text{ft.}^3}{\text{lb.}} \cdot \text{kw.}$$

From the conversion table, Table I, $\text{kw.} / (\text{lb. ft. sec.}^{-1}) = 737.3$; therefore,

$$L = \frac{0.140 \cdot 10^{-3} \text{ sec.}^2}{\text{ft.}} \cdot W^3 \cdot D^2 \cdot \gamma$$

This formula is complete in itself. No additional explanations are needed, any standard amounts can be used for measuring the magnitudes of quantities W , D and γ , and the result is not a number of kw. or ft. lb. per sec. but a certain amount of power which can be represented as a multiple of any desired standard amount of power. The factor $0.140 \cdot 10^{-3} \text{ sec.}^2 \text{ ft.}^{-1}$ is the "constant" of the formula, and is a definite physical quantity but not a number at all. It can be expressed symbolically, by writing, e.g.,

$$L = K \cdot W^3 \cdot D^2 \cdot \gamma$$

where K is a constant quantity of the nature of the reciprocal of acceleration. When determined experimentally, K will be found

equal approximately to $0.14 \cdot 10^{-3} \text{ sec.}^2 \text{ ft.}^{-1}$, which is the same as $0.74 \cdot \text{sec.}^2 \text{ mile}^{-1}$ or $0.46 \cdot 10^{-3} \text{ sec.}^2 \text{ met.}^{-1}$ or $0.0045/g$, where g is the acceleration due to gravity, etc.

For example, given the foregoing formula, we desire to determine the power loss in a certain case. We know that the peripheral speed is $W = 3000 \text{ met./min.}$, $D = 3 \text{ ft.}$, and $\gamma = 5 \cdot 10^{-6} \text{ gm./cu. cm.}$ Then

$$L = \frac{0.140 \cdot 10^{-3} \text{ sec.}^2}{\text{ft.}} \left(\frac{3000 \text{ met.}}{\text{min.}} \right)^3 (3 \text{ ft.})^2 \left(\frac{5 \cdot 10^{-6} \text{ gm.}}{\text{cm.}^3} \right) \\ = 0.140 (10^{-3}) (27 \cdot 10^9) (9) (5 \cdot 10^{-6}) \left[\frac{\text{sec.}^2 \text{ met.}^3 \text{ ft.}^2 \text{ gm.}}{\text{ft. min.}^3 \text{ cm.}^3} \right]$$

By reference to a conversion table the factor in brackets is found to be

$$\frac{278 \text{ ft.} \cdot \text{gm.}}{\text{min.}}$$

So that the result is

$$L = 47,288 \text{ ft. gm./min.} \\ = 0.24 \text{ kg. met./sec.}$$

The term "pressure" must be used exclusively to designate the surface-rate of force distribution. It is not permissible to use the same term when meaning an amount of force, e.g., thrust or load. The nature of pressure $[p]$ can be expressed as $[f l^{-2}]$, where $[f]$ is the nature of force and $[l]$ is the nature of length.

The term "specific weight" must not be confused with "density." The specific weight is the volume-rate of weight distribution, while the density is the volume-rate of mass distribution. The nature of specific weight is $[\gamma]$ or $[f l^{-3}]$. A standard amount, $\text{kg. met.}^{-3} = 0.06242 \cdot \text{lb. ft.}^{-3}$. Here kg. is not the mass but the weight of a body whose mass is one kilogram. This ambiguous but convenient practice has been firmly established by custom in direct opposition to the intentions of the fathers.

Specific volume is the reciprocal of specific weight and must not be confused with volume. The volume of one pound of air is still a volume, the volume per (every) pound is a new quantity, specific volume, spaceability, the weight-rate of volume; the nature of specific volume, $[S]$ or $[f^{-1} l^3]$.

Temperature is a measurable property of a body; therefore, a physical quantity. The temperature is a certain amount of temperature. The so-called temperature from zero F. or from zero C., is not the total temperature but the difference of two temperatures. The

nature of temperature is $[T]$ or $[f l \phi^{-1}]$, where $[\phi]$ is the nature of entropy.

By Coulomb's Law,

$$F = \frac{m_1 m_2}{\mu r^2}$$

where F is the mechanical force of repulsion between two magnetic masses m_1 and m_2 , distance r apart, and μ is the magnetic permeability of the medium. From this, the nature of m is $[f^{1/2} l \mu^{1/2}]$, where $[\mu]$ is the nature of magnetic permeability. The standard amount of magnetic permeability, the permeability of air, $\mu_a = \mu$. A standard amount of magnetic mass

$$\begin{aligned} \text{mg.} &= \text{dyn.}^{1/2} \text{ cm.} \mu^{1/2} \\ &= 0.5903 \cdot 10^{-3} \text{ lb.}^{1/2} \text{ in.} \mu^{1/2} \end{aligned}$$

Conversely, $\text{lb.}^{1/2} \text{ in.} \mu^{1/2} = 1649 \text{ mg.}$

Suppose we next consider magnetic field intensity. By definition $F = Hm$, where F is the mechanical force exerted by the field of

intensity H on magnetic mass m . From this, the nature of H is $[f^{1/2} l^{-1} \mu^{-1/2}]$. Standard amounts:

$$\begin{aligned} \text{gm.} &= \text{dyn.}^{1/2} \text{ cm.}^{-1} \mu^{-1/2} \\ &= 3.806 \cdot 10^{-3} \text{ lb.}^{1/2} \text{ in.}^{-1} \mu^{-1/2} \\ \text{lb.}^{1/2} \text{ in.}^{-1} \mu^{-1/2} &= 262.6 \text{ gm.} \end{aligned}$$

From Laplace's Law, as is shown above, the nature of i , electric current, is $[f^{1/2} \mu^{-1/2}]$. Standard amounts:

$$\begin{aligned} \text{cu.} &= \text{dyn.}^{1/2} \mu^{-1/2} = 1.4993 \cdot 10^{-3} \text{ lb.}^{1/2} \mu^{-1/2} \\ \text{amp.} &= 0.1 \text{ cu.} = 0.14993 \cdot 10^{-3} \text{ lb.}^{1/2} \mu^{-1/2} \\ \text{lb.}^{1/2} \mu^{-1/2} &= 6670 \text{ amp.} \end{aligned}$$

By Joule's Law, resistance is defined by $dW = i^2 r dt$, where dW is the amount of energy dissipated by current i in a conductor of resistance r during time dt . From this, the nature of r is $[l t^{-1} \mu]$. Standard amounts:

$$\begin{aligned} \text{re.} &= \text{cm.} \text{ sec.}^{-1} \mu = 0.3937 \text{ in.} \text{ sec.}^{-1} \mu \\ \text{ohm.} &= \text{re.} \cdot 10^9 = 0.3937 \cdot 10^9 \text{ in.} \text{ sec.}^{-1} \mu \\ \text{in.} \text{ sec.}^{-1} \mu &= 2.54 \cdot 10^{-9} \text{ ohm.} \end{aligned}$$



Architectural Beauty and Quiet Operation Combine to Make the Automatic Substation
an Asset to Any Neighborhood

The Electric Motor in the Crushed Stone Industry

By E. W. PILGRIM

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At the mention of the word quarry most of us think of a hillside half torn away and displaying a ragged ledge of rock. Associated with this mental picture is the thought of a small group of men drilling and blasting. Actually, a quarry for furnishing crushed stone requires in addition to manual labor a considerable amount of power for shovels, conveyors, crushers, and screens as well as for the drills. In this article the author shows that electric drive is preferable as the source of motive power and gives much valuable data on actual quarry electrification.—EDITOR.

A crushed stone property consists of a stone crushing plant situated near a natural quarry. In the quarry all work is out of doors and subject to varying weather conditions. The machines are portable and cables connecting the motors to the power line are laid along the ground; for these reasons low-voltage motors (440 or 220 volts) should be used. In the crushing plant the motors are sheltered and the larger ones may operate on 2200 volts.

Purchased power, where it is available, will be found cheaper and more satisfactory than the development of an isolated steam plant on account of the high maintenance costs of the latter. The water, if available, usually has to be pumped some distance and is generally high in impurities, which form boiler scale rapidly, requiring the renewal of boiler tubes at least once a year and sometimes oftener. High losses result from leaky steam connections and poorly insulated steam pipes. A water power at or near the property, that can be cheaply developed, may be able to compete with purchased power, but the continuity of service rendered by the power company and their ability to meet overload requirements should be capitalized.

Assuming then that electrical energy will be purchased and that the power company will deliver power at a voltage higher than 2300, an outdoor transformer substation must be provided and should be located out of range of flying stone from blasting but near the center of distribution. The outdoor transformer station for the average quarry will have three 150-kv-a. transformers, lightning arresters, switching, and metering equipment and may be of steel tower construction, as in Fig. 1 or of wooden pole construction, as in Fig. 2. A separate lighting transformer of about 10 kv-a. will be required. This transformer may be made large enough to carry one or more machine shop motors so that power will be available at times when the large transformers are disconnected.

Lighting

Good illumination is excellent insurance against accidents. Incandescent lamps should be so located that they will amply light the machinery, and where they may be renewed and cleaned conveniently. The switch for controlling the lights must be handy so that workmen will turn off lights when not needed. 60- to 100-watt Mazda lamps should be used as not enough illumination can be had from smaller sizes after they are once coated with a film of dust. A number of floodlights illuminating the working part of the quarry should be installed, and so arranged that they can be moved as the work of quarrying progresses.

Well Drills

The well drill, as used in quarry practice, is an apparatus designed to jerk a drilling tool, weighing from one-half to three-quarters of a ton, upward about thirty-six inches and then let it fall. Briefly, the drill has a derrick about 28 to 30 ft. high, which supports two crown pulleys at its upper end. One pulley is used for main drilling operations, the line running over it being fastened at one end to the drilling tool, and at the other end to the hoisting drum. During hoisting and lowering, the drum is run mechanically. During drilling, the drilling tool is fed from the drum manually either through a worm wheel or friction feed. The second pulley carries the line for the bailing tools. This line runs to a second drum.

Drilling is accomplished by a bell-crank arrangement. These drills are of either the traction or non-traction type, and are furnished for steam, gasoline, or electric drive. The driving equipment must be of the variable-speed type and must be capable of delivering high torque at low speed not only for drilling operations but also for traction requirements.

When direct current is used, the compound motor should be employed. Alternating

current requires the use of the wound-rotor induction motor. The latter type is the more common. Alternating-current equipment includes a $7\frac{1}{2}$ - to 15-h.p. motor at 720, 900, or 1200 r.p.m., for motors with sliding bases and pulleys for belt drives, the horse power and speed requirements depending upon whether or not a traction type drill is used and the drilling speeds desired. The motor control equipment consists of a reversible controller and a heavy-duty grid resistor. A rod extending from the controller to the drilling end of

Of the three classes of equipment, the electric power unit requires the minimum amount of attention, thereby permitting the driller to devote the greatest amount of time to actual drilling. The electrical unit can be started or stopped instantly, and as a rule it furnishes the cheapest power. Many plants where these drills are employed are electrically equipped throughout, thereby making the electric drill part of the standard equipment and placing it under the supervision of one man. An electric drill is the lightest type of outfit, a desirable feature in non-tractive units.

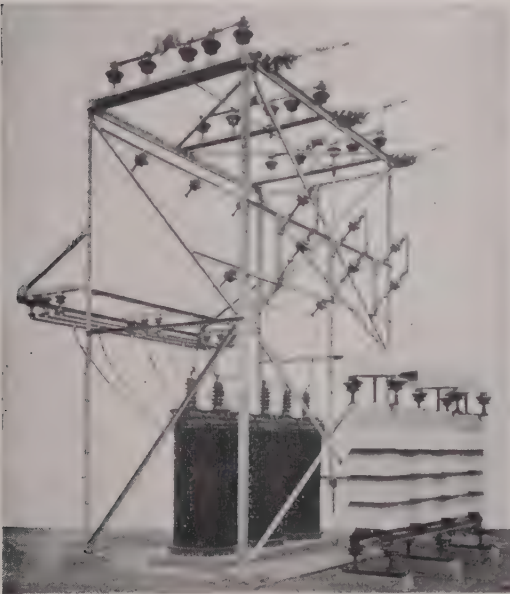


Fig. 1. Outdoor Substation Suitable for a Stone-crushing Plant



Fig. 2. Outdoor Substation Serving the Albany Crushed Stone Corporation

the machine brings the control to a point convenient for the drill man.

One argument in favor of the steam or gasoline drills is that they are self contained and can be operated over an unlimited area, entirely independent of outside power supply. Where electricity is available at the quarry, this argument is not of much consequence. The gasoline drill is, in general, to be preferred to the steam unit. The gasoline unit requires very little water which, as found around quarries, is often unfit for boiler feed. Gasoline can be easily and cheaply handled and there is no waste as in steam drilling where the fuel is usually placed in several piles near the holes that are to be drilled. The usual factors of attendance and firing which accompany steam operation are eliminated.

Shovels

For the ordinary quarry, it is usually desirable to take the stone either directly from the face or after it has been shot, and load it into mine cars with some form of power shovel. The advantages of electric drive over steam for this work are quite marked, especially where the operation is intermittent and shut-downs of 30 min. to one or two hours are liable to occur. In such cases the electric shovel has a decided advantage on account of the fact that it can be shut down completely and will not use any power, whereas the steam machine has to stand with the fires banked. An average quarry would load in the neighborhood of 800 cu. yd. of rock in a ten-hour day. To do this against a fairly stiff bank would require a shovel with about a

1½ cu. yd. bucket. A suitable shovel is one of the full revolving type having a fairly high and wide reach, and fitted with a modern caterpillar traction, giving it a wide range of operation. One of the big advantages of caterpillar traction is that the pit gang can be reduced to a minimum, thereby cutting down the operating expense.

This type of shovel will work rapidly in comparatively hard digging and can load accurately into cars with minimum movements of the loading track. It can be equipped with various types of dippers and booms to suit special local conditions.

One magnet valve.

One protective panel.

One combined resistor.

One motor-generator set.

The motor-generator set will consist of a 50-kw., 1200-r.p.m., 250-volt, direct-current generator, directly connected to a 75-h.p., 1200-r.p.m., 440-volt, or 2200-volt motor forming a 2-unit, 3-bearing set.

Equipment for controlling the motor-generator set comprises:

One starting compensator.

One disconnecting switch.

One generator field rheostat.



Fig. 3. Electric Locomotive Suitable for Hauling Cars at the Quarry

The power supply is brought to the shovel by a flexible cable about 500 ft. in length, which trails after the shovel as it moves. The equipment on the shovel should be as follows:

One 75-h.p. hoist motor, 230-volt, 485-r.p.m., series-wound mill type.

One 20-h.p. swing motor, 230-volt, 725-r.p.m., series-wound mill type.

One 20-h.p. crowd motor, 230-volt, 725-r.p.m., series-wound mill type with waste packed bearings.

One hoist control drum controller with vertical handle.

One magnet valve.

One protective panel.

One swing-control drum controller with vertical handle.

One crowd-control drum controller with vertical handle.

The functions of the hoist, swing, and crowd motors and controllers are evident. The magnet valves are used to control the mechanical brakes on the various motors. Tests have proved that air brakes are superior to electric brakes for this service. The protective panels on the hoist and crowd motions furnish an automatic form of protection to prevent burning out the motor when stalling conditions are encountered. The function of the motor-generator set is to convert the alternating-current power brought to the shovel into direct-current, which it has been found is the most suitable supply for operating the motors which are geared directly to the various motions.

Tests show the following comparative results on cost of operating shovels:

Steam, 100 per cent

Gasoline-electric, 86 per cent

Electric, 76 per cent

Electric Locomotives

Stone can be hauled from the quarry to crushers by storage battery locomotives. These locomotives are equipped with long life batteries, and are highly efficient. One of the big items of expense with each ton of stone is the haulage charge. The storage battery locomotive reduces this expense by ease of operation and low center of gravity, which allows maximum speed on tracks that are often uneven.

The storage battery locomotive shown in Fig. 3 makes grades and hauls heavy loads easily. It is provided with batteries, the

Motor Drives

Belt drive is universal, because if a crusher, screen or conveyor becomes clogged, the belt will slip and no damage is done; if geared, a similar clogging would strip the gears or break some part of the machine. Then, too, the belt prevents vibrations from the crusher being transmitted to the motor. Individual drive is general, although there are some plants in which the entire crushing mill, including possibly three or four crushers with their elevators and conveyors, is driven in a group from one large motor.

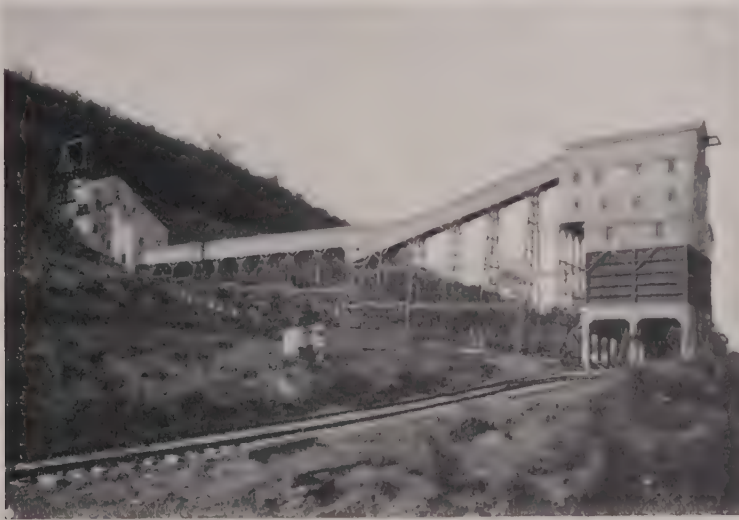


Fig. 4. Quarry and Crushing Plant of the Albany Crushed Stone Corp. at Feura Bush, N. Y.

upkeep and repair costs of which are extremely low. There is always extra power when it is necessary to couple on an extra car.

Crusher Plant

Fig. 4 shows a general view of a crusher plant including conveyors and storage bins. In the crushing plant, devices involving motor drives are:

- Crushers
- Screens
- Bucket elevators
- Belt conveyors

It is very dusty in the crushing plant, and, if possible, the controllers for the motors should be grouped in a dust-proof room. The motors will be started from this one point, but stop buttons should be placed near the machines for emergency stops. Fig. 5 shows such a group of controllers.

The starting torque required is small unless the unit is accidentally stopped with material in it, in which case it is usually necessary to dig it out before it can be started even with a wound-rotor induction motor. The application of either induction or synchronous motors is good practice. The former makes the simpler installation, but it imposes more severe starting conditions on the system, which are undesirable in some plants where fairly large crusher motors are used. The crusher motors usually run over a rating of 100 h.p. and they should, therefore, be furnished with an outboard bearing.

Care must be exercised to see that belt centers are in line and pulley diameters and belt widths liberal. A ratio of not over 3 to 1 between the crusher speed and motor speed is considered good practice.

Crushers

The first crusher is either of the gyratory or jaw type. This crusher reduces the stone to three or four-inch pieces. From the first crusher the stone is passed through a rotary screen where the small pieces (about 10 per cent) are screened out and the remainder is discharged into two small gyratory crushers where it is reduced to commercial sizes. Fig. 6 shows a gyratory crusher drive. Upon leaving the second crusher, the stone which is too large to go through the screen is conveyed by bucket conveyor back to the crusher. The stone which is of commercial size drops on a conveyor to be carried to the storage bins. Here it is passed through sizing screens where it is separated as to size and deposited in separate bins.

When crushers are fed intermittently as, for example, the very large crushers which take the material when it first comes from the quarry and which are of such great capacity that they can run a small car load of rock through in less than a minute or two, after which they run light for some time, the driving motor can be somewhat smaller than for crushers of the same size fed from bins when the power required is more nearly continuous. In general, experience shows that these crushers are over-motored so that available horse power data are more likely to be high than low.

Jaw Crushers

In this type of crusher, the grinding takes place between two jaws, one fixed and one movable, and together forming an acute angle. The jaws are usually faced with corrugated plates made of chilled iron or manganese steel or some other similarly tough metal. The feed opening at the top of the crusher is larger than the discharge opening at the bottom and gravity brings the material into the crushing zone and discharges it when crushed. The movable jaw is suspended from the top of the crusher frame and is given a reciprocating motion by means of an eccentrically operated vertical pitman and a pair of toggle plates.

Jaw crushers have heavy unbalanced reciprocating parts and hence require large flywheels and heavy foundations. The moving parts of this type of crusher are heavy and make necessary driving equipment capable of delivering fairly high torque at starting. The wound-rotor induction motor is the best application and should, in general, be recommended. As in the case of the gyratory

crusher, individual belt drive is usually employed. For the crusher sizes, suitable for average stone mill operation, it is well to furnish a motor with an outboard bearing.

Hammer Mills

These mills are made in a number of styles and sizes, and by several manufacturers, but they all embody the same general features. Briefly, the machine consists of a row of hammers hung loosely from bolts running through disks mounted on a substantial shaft



Fig. 5. Control Room for Crusher and Screen Motors

revolved at high speed and encased in a suitable housing. The hammers first reduce the material against the breaker plate, then carry it over the cage or grating where oversize material is subjected to further blows by the hammers until it is of proper fineness to pass through the openings. By varying the number, shape, and weight of the hammers, the type and opening of grates, and the forms and arrangement of breaker or grinding plates, stone can be reduced to practically any desired fineness. From the above, it will be seen that these machines are adaptable to high ratios of speed reduction.

As may be imagined, the load on the hammer type of mill is subject to rapid fluctuation and especially so if the mill is not operating under a steady feed. Most mills are, therefore, provided with flywheels. The rotating element of the mill itself is heavy and, since the unit operates at high speed, the total

flywheel effect is relatively high. Considerable torque must accordingly be applied to bring the mill up to speed within a reasonable time. The manufacturers state that hammer mills should never be started with material in them, the regular procedure being to shut off the feed some time before stopping the mill, so that it empties itself and is clear when again started up. In case of accidental shut-down with material in the machine, it should



Fig. 6. 200-h.p., 2200-volt Slip-ring Motor Driving a 42-in. Gyrating Crusher

be cleaned out before starting. Some mills are provided with dumping features, but this is the exception rather than the rule, most mills being so constructed that the material actually has to be dug out—a rather laborious task. To attempt to start a loaded motor-driven hammer mill with material in it will very probably lead, sooner or later, to trouble with end rings of squirrel-cage motors, or with starting resistances of wound-rotor or direct-current motors.

Wound-rotor induction motors with heavy starting resistance are undoubtedly the best adapted for this class of work, but, since the squirrel-cage motor entails the simpler driving equipment, it is extensively used. Experience has shown that squirrel-cage motors, if of ample size to drive the mills when running and if designed with good starting torque and good end-ring construction, can ordinarily start and bring these mills to speed satisfac-

torily in spite of the heavy accelerating torque necessary.

In electrically operated plants, hammer mills are usually driven by individual motors, either belted or direct-connected. The high speeds of the mills makes direct connection easy and this form of drive should, in general, be recommended, for it makes the most economical and compact form of drive, and eliminates the cost of belting upkeep which is apt to be an appreciable item with these machines. When direct connection is employed, flexible couplings should be used as these mills vibrate considerably.

Screens

Screens are usually cylindrical, from 2 to 6 ft. in diameter and from 12 to 30 ft. long, made of heavy steel boiler plate and divided along their length in three parts, each part being perforated with different sized holes. They are set at an angle to the horizontal so that the stone will pass along by gravity and as the screen revolves slowly, the small sized stone fall through the holes. At the end of the screen and around its circumference is a bevel gear which meshes with a bevel pinion mounted on a jack shaft which is belted to the motor. The motor and starting equipment for such a drive is shown in Fig. 7.

The power required depends upon the size of screen and usually the motor driving the screen also drives the bucket elevator which returns to the crusher the stone that is too large to go through the screen holes.

TABLE I

Diameter of Screen Inches	Length of Screen Feet	H.P. of Driving Motor
72	30	40
72	24	30
72	20	25
72	16	20
60	30	25
60	24	20
60	16	15
48	20	20
48	16	15
48	12	15
40	20	15
40	16	10
40	12	10

Screens revolve very slowly and low-speed (about 600 r.p.m.) motors are used. The screens are started up empty and a squirrel-cage motor can be applied. A slip-ring motor may be used, if preferred.

The power required for various sizes of screen and bucket elevator is shown in Table I.

Conveyors

Continuous conveyors are usually the most economical means of mechanically loading and unloading loose bulk material and for moving it short distances. By the term *continuous conveyor* is meant those types of machines which keep the material moving forward in a constant stream, or in separate amounts following each other so closely that this result is approximated. This class of machines may be divided into three groups; elevating only, elevating and conveying, and conveying

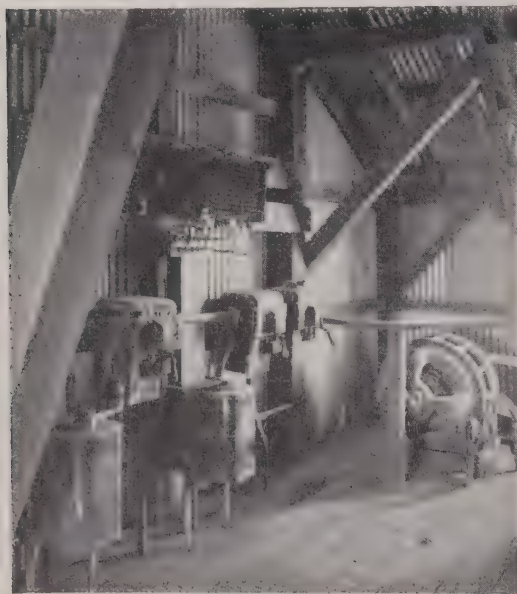


Fig. 7. 40-h.p., 2200-volt Slip-ring Motor Driving a 60-in. by 24-ft. and 48-in. by 20-ft. Screen

only. Machines for elevating only are almost without exception of the bucket type. Machines for elevating and conveying are also ordinarily of the bucket type, either of the V-type bucket or pivoted carrier bucket form. Machines for conveying only, include belt conveyors, apron and pan conveyors, screw conveyors, etc. Where material is to be loaded from a storage pile to wagons a portable conveyor may be used to advantage. Slip-ring motors should be used on conveyors, the size depending upon the length and amount of incline. Fig. 8 shows a belt conveyor.

Miscellaneous Equipment

Air drills are used for drilling blast holes in the pieces of rock that are found after the main quarry blast. These pieces are too large to be handled by the crushers and are broken



Fig. 8. Belt Conveyor Driven by 15-h.p. Squirrel-cage Motor. Vertical section at the end is driven by a 20-h.p. squirrel-cage motor



Fig. 9. 50-h.p., 3-phase, 440-volt Motor Driving an 18- by 36-in. Single-drum Hoisting Engine

up by the blasting. Air is supplied from a portable electrically driven compressor. Here the size of the motor will depend upon the make of drill and compressor chosen, and

will be about 25 h.p. per drill. Either squirrel-cage induction or synchronous motors are used.

Quarry pumps are usually of the centrifugal type and driven by the squirrel-cage motors, the size depending upon the capacity of the pump.

Where the quarry is located on the side or top of a hill, a hoist will be required to elevate tools, equipment and miscellaneous

fuel handling, and other intangible advantages accompany electric drive. Electricity also eliminates the problem of water supply in localities where water is scarce, or of poor quality for boiler use.

The average quarry will require for electrification:

- One outdoor transformer substation
- One bank of power transformers
- One lighting transformer



Fig. 10. Vertical Winch Used for Hauling Freight Cars

material from the lower level to the quarry. This hoist will usually be purchased with the motor and control forming part of the unit. Slip-ring motors are used. See Fig. 9.

For spotting cars an electric winch is manufactured as a complete self-contained unit. Having all gears, motor controller, and resistance enclosed in the winch case, the unit is compact and especially adapted to out-of-door service. One of these units is shown in Fig. 10.

Summary

There are several advantages accruing to the use of electric quarry equipment which cannot be expressed directly in dollars and cents, but which, nevertheless, require consideration. Extreme ease of control, increased speed of operation, cleanliness, elimination of

- An adequate equipment of 60- to 100-watt Mazda lamps with sockets, switches, and wiring
- Two to four floodlights
- Twelve to fifteen motors
- One or two blast hole drilling machines
- One or two quarry pumps
- One electric hoist
- One electric shovel
- One electric locomotive
- One electric winch

From the census of mines and manufacturers of the United States, the crushed stone industry at the present time proves to be 50 per cent electrified, consuming approximately 840,000 h.p. which is delivered by 12,000 electric motors. From this it can easily be inferred that electrification in this industry is meeting with a deserved success.

A Study of Liquid Dielectrics

PART I

EFFECT OF MOISTURE AND AIR CONTENT

By DR. WHEELER P. DAVEY and THOMAS A. WILSON

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

Because an adequate knowledge of insulating phenomena is essential to produce the best electrical operation, and because the operating requirements of today and those anticipated for tomorrow are becoming increasingly severe, intensive study is being given to all branches of the problem of insulation with the result that gradually there is being established a more sound theoretical background upon which to base design and practice. In the experiments which the present articles will describe, the authors have adopted the ingenious plan of testing linseed oil, which, although not an insulator of the first rank, possesses many of the characteristics of transil oil in an exaggerated degree, and with the advantage over the better oil that it lends itself to a more marked and rapid determination of these characteristics experimentally. With the information thus gained we are better equipped to proceed with our attacks on the problem of discovering what insulating action really is.—EDITOR.

Introduction

A perfect insulator has been described as a substance possessing the heat conductivity and the ductility of copper, the flexibility of rubber, the tensile strength of steel, and the electrical resistance of sulphur or mica.⁽¹⁾ All substances may be classified as being either conductors or insulators—two classes between which no sharp dividing line can be drawn. The electrical industry is chiefly interested in the two extremes: the materials which are the best conductors, and those which are the poorest, or, in other words, are the best insulators. The writers have attempted to study both of these classes. The present series of articles has to do only with the second.

Conductors and Insulators

Although no sharp dividing line can be drawn between the two classes, the technique employed in studying insulators must be quite different from that used in studying conductors. In the case of conductors, it is possible to vary one experimental condition such as the temperature without producing any appreciable disturbance in any other experimental condition. In the case of insulators, few, if any, of the variables are independent.⁽²⁾ A change in the temperature of an oil, for instance, affects its colloidal content of moisture, air, undesirable organic material, etc.; under certain conditions it may alter the chemical composition; it alters the break-down potential and the power-factor; it may even change the relationship previously existing between the current leak and the impressed voltage. This impressed voltage

also may be varied over a wide range in studying conductors. In studying insulators, the range of voltages possible is rather limited. It must be high enough to furnish a measurable current leak, yet it cannot in any case exceed the break-down potential.

Theory of Break-down

This break-down potential is one of the most characteristic properties of insulation. Much of the work reported in the literature dealing with the electrical peculiarities of insulating materials lays great stress on the measurement of this so-called "dielectric strength." Although the present authors realize the importance of this property, they believe it to have been over-emphasized. Hayden and Steinmetz⁽³⁾ consider insulation failure to be caused largely by high temperature which may be extremely localized. With this view the present authors agree.

There are two possible sources of this heat. One is a loss in energy caused by a distortion or possibly by a re-orientation of the atoms (or sometimes of the molecules) of an insulator when subjected to an alternating electric field. In the case of unidirectional voltage this effect is entirely absent except for an infinitesimal period of time immediately following the application of the voltage. It is usually quite negligible for alternating voltages except in the case of the highest radio frequencies, as shown by a consideration of the moments of inertia of the component molecules. The other source of heat is the current leak through the insulator. Any path for this leak must experience a rise in temperature, since the wattage passed through a small area, even with very small current flow, is enormous at

(1) Skinner, *Elec. J.* 17, 139 (1920).

(2) Shrader, *Elec. J.* 16, 334 (1919).

(3) Hayden and Steinmetz, *Elec. World*, 80, 865 (1922).

high voltages. This temperature rise makes the path more conducting, causing the concentration of still more energy in the original area. Unless the insulator or its surroundings can dissipate this heat, break-down must occur. This is consistent with the well-known fact⁽⁴⁾ that there is no simple relation between direct-current and alternating-current peak disruptive voltages for some insulators, and also with the fact that the voltage necessary for break-down depends upon the length of time the voltage is applied.

From this viewpoint the measurement of current leak in insulation under various experimental conditions becomes of much greater importance than the puncture-strength as a criterion for insulation. While the break-down test destroys the sample and merely shows the utmost which the insulator can stand under a given set of conditions, the measurement of current leak permits a repetition of the experiment from time to time on the same sample so that the method offers hope of finding the mechanism of the break-down and a clue to possible remedies. Because of the greater ease and accuracy of measurement, the direct-current leak offers in most cases a better criterion than the alternating-current leak, although under certain conditions to be described later, a measurement of the latter quantity is necessary.

Liquid Dielectrics

The investigation was purposely limited to the study of liquid dielectrics. Under any given set of conditions a liquid insulator may be regarded as having the general properties of a solid insulator, but because of its mobility, it shows to an exaggerated degree the resultant phenomena experienced by the solid. For instance, if solid insulation under a given set of conditions contains colloidal moisture, an oil exposed to the same conditions will acquire more, and if any rearrangement of the colloidal particles is brought about by any means, and the properties of the substance are changed because of this rearrangement, the change will be much more noticeable in the case of the liquid dielectric. Again, if the passage of a current tends to produce a chemical change in an insulator, the mobility of the atoms and the molecules of the liquid insures an exaggeration of this tendency. Because of the interdependence of all the variables encountered in insulation studies, the only way in which any one variable may be studied is by the examination

of a mass of data obtained under a variety of operating conditions. It is therefore highly desirable to use for experimental purposes a liquid dielectric.

The commonest liquid dielectrics are the mineral oils, of which transil oil is a representative. Of somewhat different nature are the vegetable oils, including the drying oils, represented by linseed oil. Transil oil possesses as its first desirable quality for an insulator a high resistance to current leak. Chemically it is relatively inert, being difficult to oxidize. Nevertheless, recent investigations have shown that transil oil can be oxidized in air, suffering deleterious changes in its electrical properties. Under certain conditions linseed oil can be oxidized much more easily, and the same changes in its electrical properties are produced, but to an exaggerated degree. Transil oil in contact with the atmosphere absorbs small amounts of water and air in the colloidal form. Under the same conditions, linseed oil absorbs these substances to a much greater degree, thus intensifying the effect of these substances on its dielectric properties. Cable insulation made from petrolatum has been known to jelly in routine use. Linseed oil is well-known for its jellying tendencies, with consequent intensifying of resulting changes in its electrical properties. Finally, whatever changes in the chemical constitution of transil oil may be produced by intense local heating, corona, or spark, will be likewise produced in linseed oil to a greater extent. For reasons enumerated, therefore, the authors have chosen linseed oil as being the best representative liquid dielectric for the present investigations.

Oils by themselves are of comparatively little use as insulators since they are devoid of rigidity. To overcome this deficiency, a spacer is used. This usually consists of paper or of some other cellulose product wound about the conductor. Subsequently this spacer is impregnated with either oil or petrolatum, thereby surrounding the cable with a layer of the liquid insulator desired. Therefore, the properties of the insulation are no longer the properties of the oil alone, but instead the properties of oil in the presence of the spacer.

As a result of the experiments to be described we believe that we have arrived at a better knowledge of the behavior of liquid insulators, and therefore (to some extent at least) of solid insulators. As an interesting by-product of the work we have been able to treat linseed oil so as to give it most of

(4) Hayden and Eddy, *J. Am. Inst. Elec. Eng.* 42, 706 (1923).

the desirable properties of transil oil in the presence of paper.

Apparatus and General Experimental Method for Direct-current Leak Tests

The experimental method for determining direct-current leak was in general similar to that described by Starling⁽⁶⁾ for the determination of the resistance of a body carrying current. The spacer impregnated with linseed oil formed the dielectric of experimental condensers across which fairly high potentials were impressed. As a source of potential, the rectified output of high-potential transformers was used. Current leak was measured with a micro-ammeter. Temperature control of the condensers was effected by placing them in thermostatically regulated ovens.

Experimental Condensers

Farmer⁽⁶⁾ has shown that the apparent dielectric strength of thin sheets of insulation increases as the size of electrodes decreases. Since comparative results were the only ones desired in this research, the electrode areas of all experimental condensers were identical.

Fig. 1 represents a diagram of one of the experimental condensers. These were made of steel, ground smooth. The outside portion *A* will be called the "cup" and part *B* integral with *C* will be known as the "disk." *C* will be called the "turret." In the top of the turret a tapering hole was drilled which served as a receptacle for the brass contact *D*. This contact was soldered to the grounded side of the high-potential circuit. The massive brass bar *F* served as the high-potential side of the circuit. The experimental condensers sat on this bar during experiments.

The cups of the condensers had an internal diameter of $3\frac{3}{4}$ in.; the diameter of the disks was $3\frac{1}{4}$ in. These dimensions provided a clearance of $\frac{1}{4}$ in. between the side of the disk and the side-wall of the cup. As will be shown later, the clearance between the bottom of the disk and the cup was 0.004 in. in all experiments, thus rendering negligible any current leak from the circumference of the disk. Forty of these condensers were used in this research.

Spacer

The spacer impregnated with the dielectric filled the space *E* (Fig. 1). As spacer a very fine grade of tough, unsized, linen paper was

used, free from visible imperfections. This brand of paper is known as "condenser paper." A large number of micrometer measurements of the sheets showed remarkable uniformity in the thickness of the paper, the sheet thickness averaging 0.5 mil.

Eight sheets of spacer were always used in assembling a condenser. These were cut out with scissors around a metal disk, so that they fitted the cup quite accurately. In the beating⁽⁷⁾ of the paper pulp minute particles of metal are apt to be imbedded in the cellulose fibers. Thus in one or two layers of paper a metallic bridge might be formed

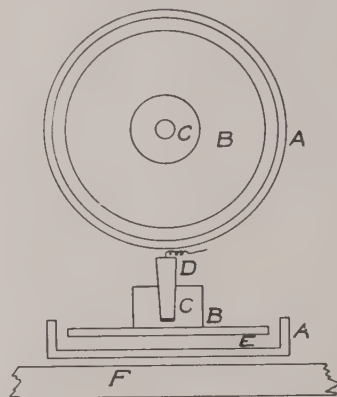


Fig. 1. Experimental Condenser

across the condenser plates resulting in a short circuit. The chance of forming such a conducting path across eight sheets of spacer is negligible. Furthermore, the probable similarity of distribution of metallic particles throughout the eight sheets would not be greatly different in different condensers, thus reducing the experimental error due to this cause. The weight of the disk was sufficient to insure the close packing of the spacer in the condenser.

Dielectric

The linseed oil used throughout this research was known as "Superior" Linseed Oil, supplied by Spencer, Kellogg & Sons. It was of a clear light amber color. On exposure to the air, it jellied without change of color and without sludge formation. The oil was kept in a well-stoppered tin can, since many investigators believe that light, of short wavelengths especially, has the ability to change the composition of raw oil.⁽⁸⁾

Different methods of impregnating the spacer with the oil were used in different experiments. These will therefore be described later.

⁽⁶⁾ Starling, "Electricity and Magnetism," Longmans Green & Co., (London) 91, (1912).

⁽⁶⁾ Farmer, *Elec. World*, 62, 1250 (1913).

⁽⁷⁾ Sindall, *Elem. Manual of Paper Technology*, Griffin & Co. (London) 44 ff. (1910).

⁽⁸⁾ Geuther, *Z. angew. Chem.* 19, 2087 (1906).

Cleaning of Condensers

After many of the experiments, the linseed oil in the condensers was oxidized either to a hard cake or to a sticky mass. In all cases, because of the presence of the spacer, the condensers were exceedingly hard to clean. Solvent agents such as chloroform, benzol, carbon tetrachloride, or mixtures of these and related liquids, left the metal surfaces coated with a thin, sticky, scum of oxidized oil.

The following procedure⁽⁹⁾ was finally adopted. As much as possible of the spacer and jellied oil was scraped out with a case-knife. The metal parts were next allowed to soak for three or four days in a concentrated solution of caustic soda, which changed the hard, oxidized skin to a soft pulpy mass which could be quite easily removed with a piece of waste. This treatment, however, was quite apt to discolor the surfaces of the condensers. This discoloration was removed by a momentary dip in dilute hydrochloric acid and a rub with waste. In case the discoloration persisted, the condenser was dried and polished with a little fine emery paper. Finally, all traces of acid remaining were neutralized by dipping the condenser into dilute caustic soda solution. The condenser was then thoroughly washed and dried.

Ovens

The working temperatures of the condensers were controlled by constant temperature ovens. Fig. 2 represents a cross-section of an oven, parallel with the front wall.

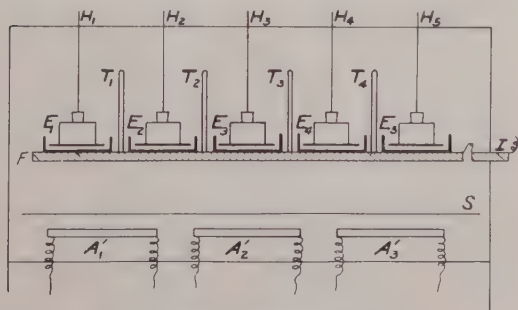


Fig. 2. Vertical Cross-section of Oven

These ovens were built of heavy asbestos board bolted to an angle-iron frame. The heating elements of each oven were three 1000-watt broiler grids (A_1' , A_2' , A_3') supported on porcelain insulators. As will be noticed from the wiring diagram, Fig. 3, these heaters were connected in parallel, but only A_2' was

so connected as to be controlled by the constant temperature control G . Above these heaters was supported a copper sheet (S , Fig. 2) almost as large as the floor of the oven, serving as a baffle plate to equalize any temperature differences which might result from the intermittent working of the middle heater. Above this plate were the two heavy brass bars F on which the experimental

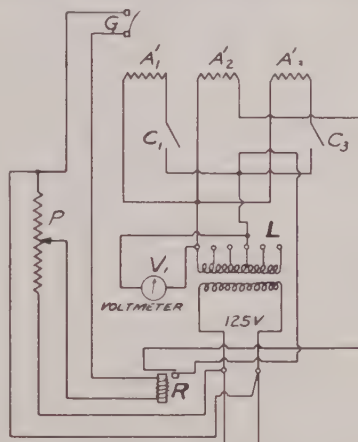


Fig. 3. Heating Circuits for Oven

condensers were placed as shown at E_1 , E_2 , E_3 , E_4 , E_5 . A three-inch clearance was maintained between these high-potential bars and all surrounding surfaces by supporting them on long porcelain insulators. Mercury thermometers T_1 , T_2 , T_3 , T_4 , inserted into little wells drilled into the brass bars showed the temperatures of the different positions.

The method of temperature control is shown in Fig. 3. L was an auto-transformer used to regulate the voltage across the grids A_1' , A_2' , A_3' . This voltage could be read by the voltmeter V_1 . The thermostat metal regulator G situated near the center of the oven controlled the grid A_2' by means of the relay R . The proper voltage for the relay was furnished by the potentiometer rheostat P . For temperatures only slightly above that of the room the middle heating grid was used alone, the grids A_1' and A_3' being disconnected by the switches C_1 and C_3 .

The high potential wire leading to the bars was introduced through the wall of the oven at I (Fig. 2) by means of the insulator shown more in detail in Fig. 4. This insulator consisted of two concentric glass tubes separated on the inside of the oven by an asbestos washer and on the outside by a rubber stopper. No leakage of the current across to the

⁽⁹⁾ Recommended by Mr. C. Van Brunt, of this laboratory.

oven wall was observed at any time during our experiments. The ground wire from each condenser turret (H_1 , H_2 , H_3 , H_4 , H_5 , Fig. 2) was led out through a small hole drilled through the top of the oven.

The condensers while in the oven could be observed through the door, which was made of a sheet of plate glass, sliding in grooves. Safety switches were so arranged

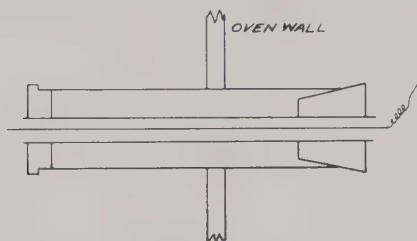


Fig. 4. High-potential Insulator

that the oven door could not be opened without at the same time opening the primary circuit of the high-potential transformer.

Two such ovens with independent heating circuits were used. Each oven contained two brass bars, lettered *A*, *B*, *C*, and *D*, as shown in Fig. 5, which represents a horizontal cross-sectional view of the ovens. Each condenser position was numbered as shown for purposes of record. Each condenser was also stamped with a number. Bars *A* and *D* were connected to one source of high potential, and bars *B* and *C* to another. Thus it was possible, working with two different oven temperatures and two different high potentials to secure data on four different combinations of conditions at a time. This was the procedure ordinarily followed.

Sources of High-potential Current

Fig. 6 represents the arrangement made to supply high-potential current to each pair of oven bars as explained above. *N* was a transformer capable of delivering 30 kv. from the secondary. This secondary output, rectified by the kenotron *K*, was led to the high-potential bar *F*. The condensers on the bar were grounded through the multiple jack switch *J* shown more in detail in Fig. 7. It will be noticed that closing this switch first makes contact through the micro-ammeter circuit, then breaks the original circuit to ground. *M* represents the micro-ammeter. This instrument with the shunts provided could be used to read from 0.01 micro-amp. to 8000 micro-amp.

The primary voltage of *N* was regulated by the auto-transformer *L*₁. The impressed voltage across any set of condensers was read by means of an electrostatic voltmeter *V*₂. In actual practice, two of these were used, one reading up to 5 kv., the other up to 20 kv. They were so connected that the 5 kv. meter would not read unless the 20 kv. meter was first connected in. This was accomplished by high-potential switches of original design worked at a distance by cords. No leakage across the switches could be detected.

Filament current for the kenotron was supplied by the step-down transformer *L*₂ regulated in turn by the auto-transformer *L*₃. In actual practice, two of these kenotrons were connected in each high-potential circuit so that either half of the alternating-current cycle from the secondary of *N* could be used at will, thereby forming a convenient high-potential reversing switch. This feature of the apparatus was of value in studying the action of current reversal on the experimental condensers.

To prevent leakage at all points in the system, all high-potential wires were enclosed in one or two thicknesses of glass tubing. This tubing extended well over all transformer terminals and all other exposed conducting parts. Wherever a massive piece of metal formed part of the high-potential circuit, as in the ovens for instance, all its edges and

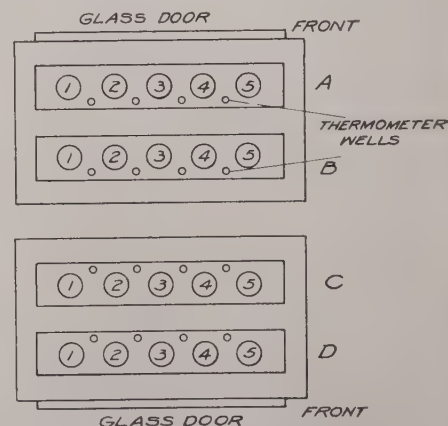


Fig. 5. Horizontal Cross-section of Ovens

corners were rounded off to prevent corona. Bare wires were used throughout for high-potential transmission, so avoiding all projecting threads of insulation for the same reason. The micro-ammeter, which was apparently sensitive to high-frequency waves throughout the laboratory was carefully

screened by covering it with a grounded copper box provided with a tight fitting cover. For safety, the whole apparatus was enclosed in a grounded wire screen, and all doors and openings were provided with safety switches which opened all high-potential circuits when the doors were opened.

It will be noticed that no filter was provided as is usual in kenotron alternating-current rectification. This was not considered necessary for two reasons. In the first place, the experimental condensers furnished considerable capacity in the high-potential circuit since it was usual to have at least six condensers supplied simultaneously by each high-potential transformer. In the second place, the currents passed by these condensers were small, as reference to the tables shows.

EFFECT OF MOISTURE AND AIR CONTENT OF LIQUID DIELECTRICS ON DIRECT-CURRENT LEAK

According to Evershed⁽¹⁰⁾ moisture content determines the excellence of resistance of an insulator. The authors attempted to verify this conclusion in a preliminary experiment. Two sets of condensers were assembled in exactly the same manner. One set was heated to 108 deg. C. for 5 hours; the other set was not heated. Under identical experimental conditions the ratio of the direct-current leak of the latter set to that of the former was approximately 50:1; a result in accordance with the observations of Shrader.⁽¹¹⁾

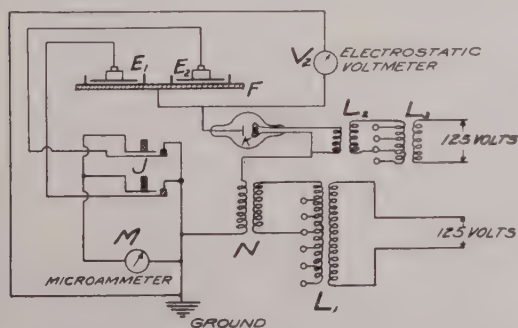


Fig. 6. High-potential and Rectification Circuits

Subsequently it was found that direct comparison of the direct-current leak of condensers containing dried spacer with those containing spacer saturated with water vapor under various conditions was never satisfactory owing to the enormous differences in their

resistances. To illustrate this fact, one such experiment will be described.

The dry condensers contained spacer which had been heated to 125 deg. C. for 2 hours in the air. The moist condensers contained spacers which had been treated with saturated steam for the same length of time. Immediately after placing both sets on the high-potential bars, a potential of 55 volts was applied across all of the condensers. (This voltage was measured by means of an ordinary voltmeter connected across the electrostatic



Fig. 7. Jack Switch

voltmeter.) While the moist condensers showed a leakage of thousands of microamperes, the dry condensers showed no reading.

The original moist condensers were removed and others substituted in which the spacer was used at room conditions of saturation. The results are given in Table I. Leakages are expressed in microamperes (mc.-a.); resistances in megohms (Ω). Set "A" was kept at room temperature as shown in the table, while Set "B" was kept at an elevated temperature. The experiment lasted 24 hours, but high potential was applied only when readings were being taken. As explained above, the leakages through the cold dry condensers were too small to be read on the micro-ammeter,

TABLE I
Preliminary Direct Comparison of Dry and Moist Condensers

SET "A"					
Time	At start		After 24 hours		
Temperature	32.5 deg.		31.8 deg. C.		
Impressed Voltage	1900		2300		
Description	mc-a.	Ω	mc-a.	Ω	
Dry condenser	...	...	...	...	
Dry condenser	...	...	...	...	
Moist condenser	4.05	469	5.68	405	
Moist condenser	2.54	749	3.85	598	
Moist condenser	3.32	573	5.58	412	
SET "B"					
Time	At start		After 24 hours		
Temperature	87.5 deg. C.		93.0 deg. C.		
Impressed Voltage	1900		2300		
Description	mc-a.	Ω	mc-a.	Ω	
Dry condenser	0.52	3760	3.48	660	
Dry condenser	1.04	1880	5.16	445	
Moist condenser	309	6.48	352	6.40	
Moist condenser	514	3.89	377	5.97	
Moist condenser	351	5.70	361	6.23	

⁽¹⁰⁾ Evershed, *Electrician*, 71, 318 (1913).

⁽¹¹⁾ Shrader, *Elec. J.* 17, 157 (1920).

although readings could be obtained easily from the other condensers. The ratio of leakages through the moist condensers and the dry condensers in the hot oven is seen to have been about 300:1 immediately after preparation. After 24 hours the ratio had decreased to 100:1.

Effect of Water Vapor and Air contained in the Spacer on the Absorption of Linseed Oil by the Spacer

In dissecting these condensers, it was noticed that all contained bubbles distributed throughout the dielectric layers. These bubbles were small (pin-head bubbles) and rare in the dry condensers, but they were much larger and more numerous in the moist condensers. With the exception of one lot of spacer sheets to be described in detail later no spacers showed visible moisture at the start of the experiments, i.e. at room temperature. A number of condenser cups were filled with spacer which had been saturated with water vapor at room temperature for 6 days. Half of the cups were warmed in an oven for one hour at 110 to 118 deg. C. The other half were not warmed. Linseed oil was poured over the paper of both sets. At the end of 10 minutes, the spacers of the two sets presented strikingly different appearances. Except for a central spot about $\frac{5}{8}$ in. in diameter, the paper in the dry condensers appeared to be completely saturated with oil. In the moist condensers the oil-free spot at the center was about 2 in. in diameter and the remainder of the paper became only partially impregnated with oil, showing a mass of bubbles. By squeezing several of these together and working them toward the edge of the condenser-paper, they could be finally transferred to a piece of filter paper. The oil at once soaked into the filter paper leaving a drop of water behind on the oil-soaked surface.

The dry spots in the centers were caused by air which had been entrapped by the oil. Heating the oil to 150 deg. C. at atmospheric pressure caused no effervescence, yet this hot oil bubbled violently when subjected to a moderate vacuum. Phosphoric anhydride inserted in the vacuum line became coated with a mixture of the hydrate and a black resin. The authors believe that this resin is formed by chemical action between the phosphoric anhydride and the volatile oxidation products of the linseed oil as a result of

which water is removed from the latter and tarry polymerization products are left. Apparently the vapors therefore consist of water vapor, volatile oxidation products of linseed oil, and perhaps small amounts of air. In the liquid state the first of these is probably present in a colloidal condition, thus making its complete removal very difficult.

The spacer contained a much larger amount of air and water vapor than the oil. The air is probably held mechanically by the fibers of the paper. Fairly complete removal of this impurity is possible with continued heat and vacuum treatment. The water vapor must be regarded as a more or less integral part of the paper, since it is hard to distinguish between water absorbed by the paper and water which is formed by partial decomposition of the cellulose itself. Noticeable charring of the spacer occurred in numerous instances throughout this research, and in every case the leakage shown by a condenser containing charred spacer was much higher than that shown by normal condensers. From an electrical viewpoint alone, then, complete removal of contained water from the spacer is undesirable. The temperature to which the spacer may be heated in attempts to remove this water must be carefully watched, since too high temperatures cause the formation of decomposition products of cellulose, the presence of which may be more deleterious than the presence of the original water. Obviously, too, excessive temperatures cannot be permitted in attaining the complete removal of absorbed air. Although fairly complete removal of air and water vapor was attained, the authors were never able to prepare a spacer by this method which did not show a few pin-head bubbles after the absorption of the oil.

This lack of homogeneity in the spacer layers is probably the chief reason for the variation of results obtained from different condensers under identical operating conditions. The authors are inclined to believe that by far the greatest conductivity shown by a liquid dielectric is caused by these bubbles (and probably other impurities⁽¹²⁾ held in colloidal suspension in the oil) forming short circuits from point to point within the spacer. This tendency to form conducting chains is apparently caused by the difference in dielectric constant between the disperse phase and the dispersion medium. Apparent confirmation is furnished by recent unpublished research performed by Mr. W. T. Eveleth in this laboratory. Therefore, what is desired from

⁽¹²⁾ Impurities here denote water vapor and air. The term "impurity" will be understood to refer to these substances and to other materials held in colloidal suspension in the oil.

the study of a set of condensers working under any given set of conditions is not the average leakage which they may be expected to show; on the contrary, what is desired is the variation in leakages which may be expected. For this reason, no average values are tabulated in the tables. Since the engineer is primarily interested in the worst resistance which an insulator will show, it is the usual practice to compare the lowest resistances of different sets of condensers in calculating approximate ratios between the sets.

Effect on Direct-current Leak of the Removal of Contained Air and Water from the Spacer

It has been mentioned above that absorption of oil by the spacer caused segregation of the moisture and air content of the paper, and that most of the bubbles so caused could be ironed together, rolled to the edge of the spacer and then removed. As a preliminary experiment, it was decided to find out if this ironing out of the bubbles had any effect on the direct-current leak.

Three sets of condensers were prepared, employing spacers which had been saturated with moisture at room temperature (24 deg. C) for 4 days. The condensers of Set "A" were assembled in the usual manner, without precautions to remove any foreign matter which might be entrapped or mechanically held. In Set "B," the spacer was suspended so that the linseed oil could rise through it by capillarity. The air and water were thus crowded ahead of the oil. The metal disks which formed the top electrodes of these condensers were lowered into the cups on a slant so that any air bubbles which might form beneath these disks would be squeezed out to the edges. In Set "C," the oil was poured over the spacer in the usual way, but the metal disks were again lowered on the slant. Partial ironing out of contained bubbles was thus accomplished. One condenser from each set was placed in each of the ovens; one oven being held at 34.5 deg. C, and the other at 96.0 deg. C. Immediately upon the attainment of temperature equilibrium, a low voltage was applied with the results shown in Table II. The cold condenser which was prepared with care to remove as many bubbles as possible (Set "B") shows a higher resistance than the others, but such a tendency is not much in evidence among the hot condensers. Bubbles formed on the free surfaces of the latter as they warmed up, however, showing that they were freeing themselves of undesirable impurities to some

extent, thus accounting for the anomalous results shown in the second group of Table II.

The effects of contained impurities on dielectric resistance is made apparent by the following series of experiments. These experiments yield as the final result a comparison between condensers containing saturated spacer and others in which the spacer has been purified by heating previous to the assemblage of the condensers.

Two lots of moist condensers were used. One lot contained spacer which had been saturated with steam at barometric pressure for 2 hours; the other lot contained spacer which had been saturated for twice that length of time. The spacer of the latter set showed moisture spots following its saturation period, but the former set of spacers showed no visible moisture on the surface. In both

TABLE II

Comparison of Condensers Ironed Out to Remove Air Bubbles and Moisture with Others Prepared Without Ironing Out. Spacers Saturated with Moisture at Room Temperature

Temperature	34.5 deg. C.		96.0 deg. C.	
Impressed voltage	110		105	
Set	mc-a.	Ω	mc-a.	Ω
"A" (See text)	685	0.161	1030	0.102
"B" (See text)	296	0.372	670	0.157
"C" (See text)	780	0.141	540	0.195

lots the condensers were quickly assembled before the moisture content of the paper had time to change, and were immediately placed in the ovens, one of which was maintained at room temperature; the other at a higher temperature. A third lot of condensers was prepared from spacer which had been previously dried at 150 deg. C. for 3 hours in the condenser cups before the introduction of the oil. During the preheating, the spacer in condenser 3, (Set "F," Table III) became somewhat charred, thus accounting for its rather low resistance.

The results of the different experiments have been collected in Table III. In Sets "A" and "D" are recorded the leakages obtained with the condensers saturated for 4 hours, working at room temperature and at elevated temperature respectively. In Sets "B" and "E" are recorded the data furnished by the spacer saturated for 2 hours. In Sets "C" and "F" are recorded the data of the dry condensers. The time interval which elapsed between the initial and the final readings in Sets "A," "B," "D," and "E," was 4 days, that which elapsed in sets "C" and "F" was three days. For obvious

reasons, such experiments cannot be of long duration when performed in air, owing to the chemical changes which begin in the linseed oil after a few days. In all of these experiments, the initial reading is considered the most valuable. These condensers were kept continuously at the specified temperature, but were only under voltage when a reading was being taken. Thus effects arising from the passage of an electric current were reduced to a minimum.

ings in Sets "A" and "D." At intervals during the seasoning, the temperature of the oven for Set "D" exceeded the boiling point of water. This accounts for the much higher resistance offered by the hot condensers of Set "D" compared with those of Set "E." The water content of such condensers was constantly decreasing under the effect of the higher temperature. For the same reason also there is an unmistakable tendency for the hot moist condensers to improve with age. On

TABLE III
Combined Effect of Air and Excessive Moisture

COLD CONDENSERS						HOT CONDENSERS					
SET "A"						SET "D"					
Spacer Saturated with Steam for 4 Hours. Moisture Spots Visible	Readings at Start of Experiment	Readings After 3 Days	Readings After 7 Days			Spacer Saturated with Steam for 4 Hours. Moisture Spots Visible	Readings at Start of Experiment	Readings After 3 Days	Readings After 7 Days		
Temperature	26.0 deg. C.	26.7 deg. C.	25.5 deg. C.			Temperature	93.0 deg. C.	98.0 deg. C.	93.6 deg. C.		
Impressed voltage	Too low to measure	2150	2200			Impressed voltage	Too low to measure	2100	2300		
Position	mc-a. Ω	mc-a. Ω	mc-a. Ω			Position	mc-a. Ω	mc-a. Ω	mc-a. Ω		
1	.. ..	7460	0.288 940	2.34		1	.. ..	59.5 35.4	42.0 54.8		
2	.. ..	3040	0.707 Punctured			2	.. ..	29.7 70.8	31.0 74.2		
3	.. ..	2140	1.000 510	4.31		3	.. ..	47.2 44.5	38.4 60.3		
4	7000 ..	Punctured				4	.. ..	31.3 67.1	32.2 71.4		
SET "B"						SET "E"					
Spacer Saturated with Steam for 2 Hours. No Moisture Spots Visible	Readings at Start of Experiment	Readings After 4 Days				Spacer Saturated with Steam for 2 Hours. No Moisture Spots Visible	Readings at Start of Experiment	Readings After 4 Days			
Temperature	27.1 deg. C.	28.5 deg. C.				Temperature	92.0 deg. C.	89.5 deg. C.			
Impressed voltage	2200	2950				Impressed voltage	2200	2950			
Position	mc-a. Ω	mc-a. Ω				Position	mc-a. Ω	mc-a. Ω			
1	1020 2.16	880 3.35				1	4680 0.470	122 24.2			
2	960 2.29	730 4.04				2	5920 0.372	125 23.6			
3	860 2.56	740 3.98				3	4640 0.474	122 24.2			
4	1000 2.20	750 3.97				4	4920 0.447	129 22.9			
SET "C"						SET "F"					
Spacer Dried in Air at 150 deg. C. for 3 Hours	Readings at Start	Readings After 3 Days				Spacer Dried in Air at 150 deg. C. for 3 Hours	Readings at Start	Readings After 3 Days			
Temperature	33.0 deg. C.	30.0 deg. C.				Temperature	93.6 deg. C.	97.3 deg. C.			
Impressed voltage	2500	2500				Impressed voltage	2500	2500			
Position	mc-a. Ω	mc-a. Ω				Position	mc-a. Ω	mc-a. Ω			
1	0.08 31,250	0.10 25,000				1	4.03 620	9.4 716			
2	0.06 41,700	0.11 22,700				2	2.74 912	7.2 672			
3	0.06 41,700	0.08 31,200				3 (see text)	13.4 186	18.7 259			
4	0.07 35,700	0.12 20,800				4	6.83 366	13.0 380			

The condensers containing spacer which had been exposed to steam for 2 hours gave the readings tabulated as initial readings in Sets "B" and "E" immediately upon reading equilibrium oven temperatures. Such was not the case with those condensers which had been saturated for the longer time. Upon the application of a voltage too small to be read on the electrostatic voltmeter, one of them punctured, having previously passed a current of 7000 micro-amp. Therefore these condensers were allowed to season for three days in the ovens before voltage was again applied to obtain the middle columns of read-

the other hand, there is a tendency for the dry condensers to decrease in resistance as they age. This is probably to be attributed to the water held initially in colloidal suspension in the oil, which was absorbed by the spacer to some extent as the experiment progressed.

A rough estimate of the improvement produced in the electrical properties of the cold condensers of Table III may be readily obtained if for purposes of comparison the initial readings of condensers B1 and C1 be used as typical. These condensers show the lowest resistances of their respective sets.

The ratio of the direct-current leak of *B1* and *C1* is seen to be 1020:0.08, or about 12,700:1. In the same manner, comparison of *E2* and *F4* yields the ratio 5920:6.83 for the hot condensers, or about 900:1. *F3* was not selected as typical of the hot condensers because of the charring of the spacer as has been mentioned.

Effect of the Removal of Air Alone on Direct-current Leak

It remained to show what effect contained moisture alone would have on condenser resistance after air had been removed. To find a satisfactory method of preparing condensers for this purpose, two preliminary condensers were assembled. The cup and spacer of one condenser were warmed to 110 deg. C. for 30 min., then they were evacuated over water for 30 min. longer. The pressure of the water vapor in the surrounding atmosphere was therefore the saturation value corresponding to 100 per cent humidity at room temperature. While the vacuum over water was still maintained, the linseed oil was run into one side of the condenser drop by drop from a spout and allowed to soak through the spacer by capillarity. Considerable sputtering of the oil occurred during this operation showing that air was being removed. Before the metal disk of the condenser was inserted in the cup no bubbles could be seen in the dielectric, and after the experiment only a few minute bubbles could be detected. A second condenser made with paper saturated with water vapor at room temperature was assembled in the usual way and was exhausted over water for one hour. A great quantity of air was evolved. Under test, the latter condenser showed a resistance practically equal to that of the former. Apparently, under the conditions of the experiment, the removal of air had been about the same in the two cases. Because of the saving of time and labor, this latter procedure was adopted in making up the condensers for this portion of the investigation.

Table IV gives the leakages obtained from a set of condensers assembled in accordance with this plan. The spacer used had been saturated for 72 hours at room temperature (23 deg. C.) and had then been evacuated over water at the same temperature for one hour. The readings shown were obtained as soon as the condensers had acquired equilibrium temperatures. The moisture content of

these condensers was almost identical with that of the condensers of Table II, because both experiments used air saturated with moisture at room temperature, but comparison of the results of the tables shows that the removal of air has greatly improved the effective resistance to direct-current leak. Even neglecting the effect of the higher impressed voltages of Table IV, the ratio of resistances in Table IV and those in Table II is seen to be over 140:1. Therefore, the presence of air in a liquid dielectric is just as objectionable as the presence of water. Water and air appear to be colloiddally dispersed in oil. Entrapped air tends to form bubbles,

TABLE IV

Condensers Prepared so as to Eliminate Air.
Spacers Saturated with Moisture at Room Temperature

Temperature Impressed voltage Position	SET "A"		SET "B"	
	35.1 deg. C. 1000		92.7 deg. C. 1000	
	mc-a.	Ω	mc-a.	Ω
1	35.7	28.0	220	4.55
2	19.3	51.9	340	2.94
3	48.7	20.5	360	2.78
4	38.0	26.3	520	1.92
Temperature Impressed voltage Position	SET "C"		SET "D"	
	38.5 deg. C. 2000		97.0 deg. C. 2000	
	mc-a.	Ω	mc-a.	Ω
1	186	10.7	1010	1.98
2	197	10.2	1010	1.98
3	217	9.30	1240	1.61
4	340	5.89	1650	1.21

which decrease the effective thickness of the dielectric at certain points. The entrapped air and the colloidal impurities may both form chains between the condenser plates and cause puncture.

Effect of Extreme Removal of Impurities and Volatile Oxidation Products on Resistance of Liquid Dielectrics to D-c. Leak

If a sample of oil is allowed to stand in contact with air, it tends to dissolve air. This colloiddally dissolved air tends to produce oxidation products in the oil, some of which are volatile.⁽¹³⁾ Such a sample may then be resubjected to vacuum and made to effervesce once more. The effect of the removal of these products on direct-current leak was the object sought in three experiments.

As has been mentioned above, application of vacuum alone to linseed oil produces effervescence. If the temperature is raised the effervescence becomes violent. In the first experiment, the completely assembled condensers were heated to 125 deg. C. for one

⁽¹³⁾ Sabin, *J. Ind. Eng. Chem.* 3, 84 (1911).

Ingle, *Z. angew. Chem.* 28, 272 (1915).

Ingle and Woodmansey, *J. Soc. Chem. Ind.* 38, 101 (1919.)

hour, then they were removed from the oven and subjected to a good vacuum (manometer reading about 75 cm.) for 30 min. Violent bubbling occurred which lasted for 20 min., during which time the temperature was decreasing. Alternate reheating and re-evacuation was continued without interruption until no further effervescence was produced. This lack of effervescence was considered to show the removal of at least most of the volatile constituents. Half of these condensers were tested for leak at temperatures slightly above room temperatures; the other half were tested at temperatures of about 90 deg. C. The initial readings shown by these condensers are tabulated in Table V, the cold condensers being listed as Sets "A" and "B," the hot condensers as Sets "E" and "F" with impressed voltage of 2000 and 4025, respectively. Very low leakages are shown. At the higher voltage, however, trouble was experienced because of arcing from the disks of the condensers to the cups. This was favored because of the large apparent contraction in the volume of the linseed oil which followed the removal of air from the spacer layers. This caused the oil level to drop below the tops of the disks.

The condensers were removed; enough oil was added to restore the original level, and the alternate heating and evacuation again repeated until no further action showed. The new oil level was still above the disks. The condensers now gave the results shown in Sets "C," "D," "G," and "H." In magnitude, these results are practically the same as those in the preceding sets, showing that there was no appreciable leak across the surface of the oil in the preceding experiment. This fact is of great importance, since in subsequent investigations involving the oxidation of linseed oil, such large contractions as just experienced were unavoidable.

Sets "K" and "L" represent the results obtained from condensers with which even greater precautions were taken to reduce the partial pressure of water vapor above the condensers to a minimum during their preparation. The spacer and oil used had been kept for a week at 100 deg. C. in a vacuum in the presence of phosphoric anhydride. The anhydride not only took up water directly, but finally became coated with a tarry substance such as has been described before. The assembled condensers were further subjected to this same treatment for an additional day. It was impossible to obtain any readings from these condensers in the cold oven since

they arced from the metal disks to the cups across the surface of the oil before a readable current through the dielectric could be obtained. Therefore they were only used in the hot oven.

Comparison of these resistances with those of Sets "E" and "G" shows that the gain in

TABLE V
COLD CONDENSERS

Condensers Assembled, and Subjected to Alternate Heating (to 125 deg. C.) and Exhaustion Until No Further Effervescence Was Produced

	SET "A"		SET "B"	
Temperature	36.3 deg. C.		37.2 deg. C.	
Impressed voltage	2000		4025	
Position	mc-a.	Ω	mc-a.	Ω
1	0.04	50,000	0.09	44,700
2	0.03	66,600	0.10	40,200
3	0.03	66,600	0.09	44,700
4	0.02	100,000	0.09	44,700

Same Condensers as Above with Oil Added to Submerge the Edges of the Disks, Subjected to Additional Heating and Exhaustion Until No Further Effervescence Was Produced

	SET "C"		SET "D"	
Temperature	33.6 deg. C.		34.0 deg. C.	
Impressed voltage	2000		4000	
Position	mc-a.	Ω	mc-a.	Ω
1	0.07	28,600	0.12	33,300
2	0.04	50,000	0.15	26,600
3	0.05	40,000	0.15	26,600
4	0.06	33,300	0.12	33,300

HOT CONDENSERS

Condensers Prepared as in Sets "A" and "B" Above

	SET "E"		SET "F"	
Temperature	91.5 deg. C.		93.8 deg. C.	
Impressed voltage	2000		4025	
Position	mc-a.	Ω	mc-a.	Ω
1	3.66	546	26.9	149.
2	6.44	311	67.4	59.8
3	4.80	416	63.2	63.6
4	11.6	172	75.6	53.1

Condensers Prepared as in Sets "C" and "D" Above

	SET "G"		SET "H"	
Temperature	99.6 deg. C.		101.0 deg. C.	
Impressed voltage	2000		4000	
Position	mc-a.	Ω	mc-a.	Ω
1	6.1	328	38.6	103.7
2	10.2	196	56.1	71.4
3	9.4	213	38.8	103.0
4	7.8	256	50.5	79.3

Condensers Prepared with Extreme Precaution to Remove Air, Water Vapor, and Volatile Oxidation Products. (See Text)

	SET "K"		SET "L"	
Temperature	92.0 deg. C.		88.5 deg. C.	
Impressed Voltage	2000		2000	
Position	mc-a.	Ω	mc-a.	Ω
1	1.34	1490	arced	....
2	1.19	1680	1.38	1450
3	1.20	1670	1.64	1220

resistance as a result of this extreme dehydration, combined with long continued application of heat and vacuum is of the order of 400 per cent. They show 1000 times the resistance of those condensers from which air alone had been eliminated (Table IV, Set "D"), and about 4500 times the resistance of those condensers which contained spacer saturated with moisture at 100 deg. C. (Table III, Set "E," initial readings).

Summary of Part I

(1) A laboratory method for determining the direct-current leak of condensers has been described.

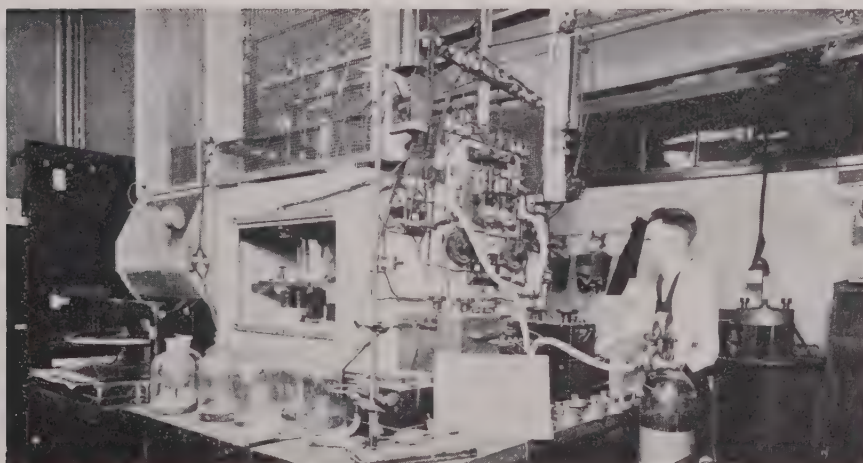
(2) Absorption of linseed oil by the spacer causes the segregation of originally contained water and air into bubbles.

(3) Removal of this contained air and water from the spacer increased the effective resistance of condensers to direct-current leak 12,000 times at room temperature, and 900 times at a temperature of about 90 deg. C. (See Table III).

(4) Removal of air from the dielectric increased the effective resistance over 140 times.

(5) Extreme removal of contained air, water, and volatile oxidation products from both spacer and dielectric increased the effective resistance to direct-current leak 4500 times at a temperature of about 90 deg. C.

(To be continued)



Apparatus Used by Davey and Wilson in Investigating Liquid Dielectrics in the Presence of Paper Spacers. The photograph was taken during an experiment in which the air over the test cells was replaced by nitrogen from the tank in the right foreground. A few of the control switches, auto-transformers, and meters can be seen at one end of the ovens. The high-potential transformers are inside the wire cage in the background. The auto-transformers shown in the right foreground were used in regulation of the oven temperature. The auto-transformers that governed the high-potential transformers, jack-switch, micro-ammeter, and electrostatic voltmeters were all placed on a control table behind the ovens. Several experimental condensers are seen in front of the oven auto-transformers; while in front of the ovens are a few of the bell-jars used to surround the condensers with a nitrogen atmosphere

The Measurement of Electrical Output of Large A-C. Turbine-generators During Water-rate Tests

By EVERETT S. LEE

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In the design of the great modern generating units, the utmost effort is expended in improving the efficiency by every possible fraction of one per cent. In the measurement of the output of such machines, therefore, it is essential that all possible means be taken to maintain a degree of accuracy commensurate with this effort in design. That determinations of such high accuracy can be made with the conventional type of portable wattmeters, ammeters and voltmeters, even when the generator load is extremely variable, is convincingly shown in this article by Mr. Lee, who outlines the procedure and analyzes the various problems which are involved. The author has conducted 40 series of output tests in the last five years on 31 machines ranging from 10,000 to 45,000 kw., and located in many different power plants; the article is the summation of his experience. We reprint it here in abstract form from the August issue of the *Journal of the American Institute of Electrical Engineers*.—EDITOR.

Introduction

In making electrical output tests on large units either for guarantee acceptance or for determining the improvement in efficiency due to advances in machine design, it is of the utmost importance that measurements be made with the maximum possible accuracy. In the tests to be described in this article all means known to the art for attaining such accuracy were made available, insofar as they could be applied under the conditions imposed when testing on commercial loads.

Instrument Connections

The usual load being connected three-phase, the three-wattmeter method was used in practically all of the series of tests because of its symmetry. The connections are shown in Fig. 1. The generator neutral being available in practically all large turbine-generators, the connections for the three-wattmeter method are easily made, a set of instruments being connected into each phase. Values of phase voltage, current, and power are thus measured directly, from which measurements the phase power-factor can be readily calculated. These values are required for making the necessary corrections to the readings of the wattmeters. Since the phase power unbalance is usually not more than two or three per cent, the three sets of instruments are operating under practically identical conditions which is an advantage both when comparing the instruments and applying corrections, and in operating with them. There is no disadvantage as regards measurement, however, if the phase unbalance is large, as the phase values are directly measured in each case. Since the phase power-factor is the same as that at which the wattmeters are operating, and since the former is rarely less than 0.8,

the wattmeters are operating under their best condition, which is near to unity power-factor.

The two-wattmeter method was used in some series of tests. The connections are shown in Fig. 2. The two-wattmeter method requires less equipment and one less observer than the three-wattmeter method, but it is not symmetrical because the phase relation between the current and voltage supplied to the respective wattmeters differs from that of the load, and is different in the respective wattmeters. The actual conditions as regards the current, voltage, and phase relation between them for the individual wattmeters can be determined from the well-known relations existing when measuring three-phase power by the two-wattmeter method. These values must be known when determining the conditions under which the wattmeters are to be compared, and when correcting the wattmeter readings later during test. Except at unity power-factor load the indications of the two wattmeters will be at different portions of the scales; this requires that consideration be given the wattmeters individually as to the suitability of scale range. When the load power-factor is 0.8, current lagging, and load balanced, the low-reading wattmeter is operating at a power-factor of 0.39. This is not the best operating point of a wattmeter as regards power-factor. If the generator neutral is grounded and a ground occurs at any other point on the system, the power may not be correctly measured. For this reason the generator neutral should be ungrounded during test.

Experience does not indicate that there is any real difference in the over-all accuracy of a water-rate determination whether the three-wattmeter method or the two-wattmeter

method is used, provided that the existing conditions are determined and the proper corrections made for them in each method. Where a large number of series of tests are to be made under widely varying conditions, it is felt that these conditions can be determined and the necessary corrections applied more easily when using the three-wattmeter method. For this reason the latter method has been generally used, in spite of the increased equipment and additional observer required, and the uniformly satisfactory results obtained thereby have justified this selection.

Instruments

Portable indicating wattmeters have been chosen for measuring the electrical output because of their superior characteristics, particularly as regards their permanency. Portable test meters have usually been used in parallel with the indicating wattmeters as shown by the connections Figs. 1 and 2. This was done to study the operating characteristics of both indicating instruments and portable test meters.

For water-rate tests, where sustained accuracy is required, instruments exhibiting the most permanent calibration characteristics should be used. In order to select such instruments from any group available, they should be compared regularly with secondary standards and a careful record should be maintained of all such comparisons made.

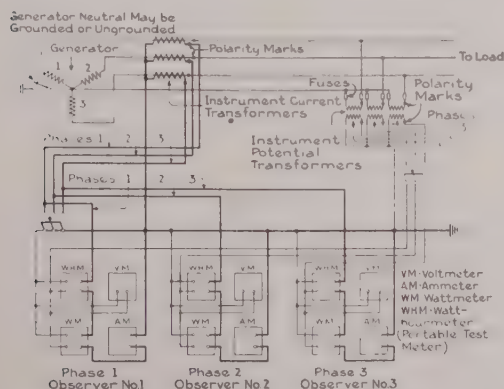


Fig. 1. Diagram of Connections and Table Layout for Measuring Electrical Power in a Three-phase Circuit Using the Three-wattmeter Method

By means of such a record over a number of years the instruments of greatest permanency will be disclosed. Such a procedure is of greatest importance and should be regularly followed, especially with the wattmeters. Table I shows the results of successive com-

parisons made upon a portable indicating wattmeter thus selected from a group of similarly made instruments. The wattmeter was carried from laboratory to laboratory by messenger. The results show no difference practically greater than 0.1 of 1 small scale division. This is typical of the performance possible from selected instruments. From such a proof of permanency of calibration

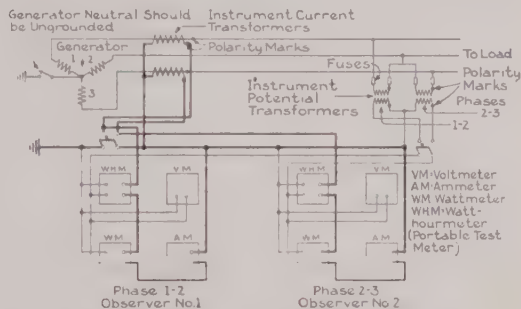


Fig. 2. Diagram of Connections and Table Layout for Measuring Electrical Power in a Three-phase Circuit Using the Two-wattmeter Method

possible in high-grade portable indicating wattmeters, the surety for sustained high accuracy throughout a series of tests is evident.

Having selected the instruments, it is necessary that they be compared against secondary standards, under conditions simulating test conditions. Ammeters and voltmeters should be compared at major scale points, with preferably the same kind of current and voltage to be measured during test. Wattmeters may be compared using direct voltage and current by using the average of direct and reversed readings. This assumes that previous measurements have been made on the instruments and standards employed to assure the correctness of such procedure. The value of the voltage maintained on the potential circuit of the wattmeter during comparison should be the test value. The interconnections of the potential and current coil maintained during the comparison should be likewise maintained during test. The value of the phase angle of the potential circuit of the wattmeter requires consideration, though in all high-grade wattmeters this is quite small, such as three to five minutes, and may usually be neglected without error in the final result.

Attention should be directed to the small scale divisions of the wattmeters to see that these are properly located. A scale wherein the small scale divisions are improperly

located should be replaced with a scale properly made. As has been mentioned, when using the two-wattmeter method, one wattmeter may be indicating at the lower end of the scale; it is necessary, under these conditions, that the scale be open at the lower end.

In order to be assured that there is no heating error in the wattmeters due to continuous operation during the water-rate test, comparisons should be made at the beginning and end of a heat run on the wattmeters at normal voltage and maximum current to be measured. If a heating error is found, correction should be made for it by using the comparison obtained with the instrument hot and then allowing the instrument to become hot before use in test. However, the best high-grade portable wattmeters have practically a zero heating error, and such instruments should be used during all tests where maximum accuracy is required.

If watthour meters are to be used, they should be calibrated and adjusted in the laboratory so as to have their best operating characteristics in the range of test values. However, the accuracy curve employed for correction during test, should be obtained "in-place" using the test current and voltage. This should be done with portable indicating wattmeters during the water-rate test. The connections shown in Figs. 1 and 2 allow for such "in-place" checks to be made. Two-minute runs, with the observer reading the indicating wattmeter as rapidly as possible, which will give 40 to 60 observations per minute, are suggested as necessary and sufficient.

A frequency indicator, or other instruments as desired, may be included in the instrument test circuit.

Instrument current and potential transformers of proper rating and accuracy characteristics should be chosen. Values of ratio and phase angle for the condition of loading equivalent to the instruments, meters and leads used during test, should be obtained by recognized means to cover the range of test values of current and voltage.

All instruments should be compared immediately before and immediately after the test series. Intermediate tests at two-week intervals may be advisable if the test series is long. Instrument transformers usually need to be calibrated only once during the test series, preferably immediately preceding it. Watt-hour meters must be calibrated "in-place," preferably immediately before and immediately after each individual test.

Observations

The instruments having been carefully selected and compared for the test conditions, they are connected into the generator line leads as shown either in Fig. 1 or 2. After checking over connections, and comparing the test-instrument readings with the available switchboard-instrument readings to see that there are no major errors, everything is ready to run a test as regards the measurement of electrical output.

Testing on commercial loads requires that means be provided for determining the readings of the indicating wattmeters over a wide range of load conditions. The load may be extremely variable, as in some railway systems, or quite steady, as in a large system of combined power and lighting. The means employed has been to take a large number of observations during the test on the theory

TABLE I
SUCCESSIVE COMPARISONS OF PORTABLE INDICATING WATTMETER, RATED
5/10 AMP., 150/300 VOLTS, 500/1000/1000/2000 WATTS. COMPARISONS MADE
ON 5-AMP., 150-VOLT CIRCUIT

Standard- izing Lab- oratory. Location. Date.	G-E Co. Schenec- tady, N. Y. 9-13-20	G-E Co. Pittsfield Mass. 9-16-20	G-E Co. Schenec- tady, N. Y. 9-18-20	G-E Co. Erie Pa. 9-20-20	G-E Co. Cleveland Ohio 9-22-20	G-E Co. Ft. Wayne Ind. 9-25-20	G-E Co. Schenec- tady, N. Y. 10-8-20	G-E Co. West Lynn Mass. 10-11-20	Bureau of Standards Washington D. C. 10-22-20	G-E Co. Schenectady N. Y. 10-29-20
Watts	Instrument Readings									
0	0	0	0	0	0	0	0	0	0	0
50	50.0	50.0+	50.0	no obser- vation	50.5-	51.0	50.0	50.25	50.7	50.25
100	100.5	100.5	100.0+	100.0+	100.5-	100.5	100.0+	100.5-	100.8	100.5
200	200.0	200.5	200.0	200.0+	200.0-	199.5+	200.0	200.0	200.0	200.0-
300	300.0	300.0	300.0	300.0	300.0	300.5-	300.0	300.0	300.2	300.0
400	400.0	400.0	400.0	401.0	399.5	400.0	400.0-	399.5	399.9	400.0-
500	500.5	500.5	500.5+	500.0	500.5+	501.5+	500.5	501.0	501.2	500.5+

0.1 of 1 small scale division is 0.5 watts.

that if the number of observations is sufficiently large, the average value obtained therefrom will be accurate to within the desired limit, and experience has justified this procedure.

The uniformly satisfactory results of many tests indicate that a test of one hour duration is ample. Table II shows results to substantiate this conclusion. If it is felt that the conditions at hand warrant tests of longer duration, several tests should be run at the longer duration and the results for each hour of the run be calculated. Such results will indicate whether the necessity for tests longer than one hour is justified. If such is the case, it is quite possible that some of the test conditions are not right and should be altered. In this connection it should be remembered that three one-hour tests at any load point, run non-consecutively, are of greater value than three one-hour tests run consecutively.

The observers for the indicating instruments should be men who are capable of comprehending the nature of the work they are doing and who recognize that their efforts should be directed towards obtaining an honest answer as to the value of the water rate of the machine under test. Their contribution to this effort is recording the readings of the indicating instruments as they honestly believe them to be. Experience obtained with high school graduates, college undergraduates and graduates, and construction men of mature years, indicates that any of these types of

men are equally suitable as observers during a test series including some dozen or two dozen tests and continuing for one or two weeks. The instructions given to all observers are as follows:

(1) Place yourself so that you are comfortable and can see the instrument scale without hindrance.

(2) Study the appearance of the instrument scale, pointer, and mirror, and have these fixed so clearly in mind that you can look at them and see them with the same familiarity as you would a book or newspaper.

(3) Read the position of the pointer on the scale over its image in the mirror just as you see it when you look at it at the designated signal with both eyes open. Read freely and without constraint. Record the value observed.

(4) At all other times rest the eyes by looking around as desired. Do not try to average readings during an interval.

(5) Do not allow your readings to be influenced by any preconceived ideas as to what the value is probably going to be. Record the result just as it appears to you at the time.

Each observer is assigned to one group of instruments. Each observer reads the indicating wattmeter at a given signal, such as a bell. Unless the observers are widely separated, no preliminary signal is necessary. Instruments are read in regular order, the wattmeter first, followed by the ammeter and voltmeter. The two latter instruments need be read only at every other signal, or in some

TABLE II

WATER-RATE FOR EACH HOUR OF TESTS OF LONGER THAN 1-HOUR DURATION

Water-rate for each hour is expressed in per cent of the water-rate obtained from the test, which value is expressed as 100 per cent

Turbine-Generator Designation Number	Test Designation Number	Duration of Test	WATER-RATE (Expressed on basis of 100% for Test Value)				Maximum Difference from Test Value Expressed in Per Cent	Type of Load
			For Test	1st Hour	2nd Hour	3rd Hour		
1	1	2 Hr.	100	100.0	99.8		0.2	{ Rapidly Fluctuating
1	2	2 Hr.	100	99.8	100.2		0.2	
1	3	2 Hr.	100	100.9	99.2		0.9	
1	4	2 Hr.	100	100.1	100.0		0.1	{ Load
2	1	3 Hr.	100	100.3	100.0	99.8	0.3	
2	2	3 Hr.	100	100.1	100.0	99.8	0.2	
2	3	2 Hr.	100	100.0	100.0		0.0	{ and Power
3	1	3 Hr.	100	100.2	99.9	99.6	0.4	
3	2	3 Hr.	100	100.2	99.9	99.9	0.2	
3	3	3 Hr.	100	99.9	100.2	99.9	0.2	{ Steady
3	4	3 Hr.	100	99.9	100.2	99.9	0.2	
3	5	3 Hr.	100	100.0	100.0		0.0	
3	6	2 Hr.	100	100.0	100.0		0.0	{ and Power
3	7	2 Hr.	100	100.1	100.0		0.1	
3	8	2 Hr.	100	100.0	99.9		0.1	

cases, every fifth signal. Watthour meters are read at the beginning and at the end of every test.

A relief observer will be necessary. The relief can be utilized also to read the values of field voltage and current, which as a rule need be read only at five-minute intervals during a one-hour test. A supervisor is necessary, together with an assistant who acts as calculator. There are thus required four observers, one calculator, and a supervisor. The supervisor will have to help the calculator after the completion of a day's run when the observers are released.

The supervisor and the observers will have to co-operate in order that the supervisor may help the observers to do their work and to detect undesirable tendencies in making observations. Rotating the observers is good practice. A good way to compare observers is, unknown to them, to connect all of the instruments in series on one set of current and potential transformers. Then run for a convenient time interval, preferably an hour, as during a test, and compare the results obtained by the individual observers.

The frequency of observation necessary has been determined from the following rule: Readings shall be taken at such intervals during a test that the average of all the observations does not differ from the average of all the alternate observations by more than an assigned value depending upon the accuracy desired. For most accurate results under practical conditions a value of 0.1 per cent has been adopted. For most commercial loads this value has been attained on one-hour tests by taking readings every minute.

Calculations

The average kilowatt output for any test is the sum of the corrected readings of the wattmeters. The corrected reading for each wattmeter for any test is equal to

$$W \times C.T. \times P.T. \times P_h$$

where: W is the average of all the corrected indications of the wattmeters, expressed in kilowatts. The correction used for each wattmeter is the average of all the comparisons which are made between it and the secondary standards.

(1) See "Revised Tables of Correction Factors for Phase Angle," C. T. Weller, GENERAL ELECTRIC REVIEW, March, 1925, and "Handbook for Electrical Engineers," 2nd Edition 1922, by H. Pender, page 1929.

(2) See "Discussion of the Precision of Measurements," by Silas W. Holman, 2nd Edition, 1904, chapter on "Direct Measurements."

$C.T.$ is the true ratio under test conditions of the current transformer to which the wattmeter is connected.

$P.T.$ is the true ratio under test conditions of the potential transformer to which the wattmeter is connected.

P_h is the combined correction factor for phase angle of the current and potential transformers and wattmeter⁽¹⁾

The kilowatt-hour output for any test is equal to the product of the average kilowatt output and the duration of the test in hours.

If when comparing any wattmeter the comparison at any point differs from the correction which has been used for previous corrections at this point by more than an assigned value (for most accurate work, taken to be 0.3 per cent of full-scale value), an additional comparison or comparisons should be made immediately at this point until their results do not differ among themselves by more than 0.1 per cent of full scale value, and the average of these results will then be taken as the value of the point in question at the time of this comparison. In the event that the excess variation (0.3 per cent of full-scale value) still remains, the new value found shall be taken as correct, and all tests in which this scale point may cause error should be investigated to determine the amount to which they have been affected. Such tests may have to be rejected. With the best, high-grade, portable indicating instruments now available, it has been found that the need for this procedure will be rare. However, a statement of such procedure is advisable for guidance if needed.

Accuracy of Final Result

A value of accuracy of the final result of the electrical output alone may be arrived at from a knowledge of the precision of the wattmeters and instrument transformers used. However, a more satisfactory accuracy figure is one which can be applied to the over-all measurement of the water rate of the turbine-generator. This figure is the per cent average deviation from the mean (defined later), and is applied to the results obtained from three or more tests at any given load point.⁽²⁾ Enough tests can be run at any load point to bring the value of the per cent average deviation from the mean within any desired value. It has been found that a value within ± 0.25 per cent can be attained in water-rate

tests wherein the measurements of electrical output are taken as are described herein and where equal care is given in making the steam-input measurements and corrections. Any individual test at a given load whose value of water rate differs from the mean value of all tests at that load by more than 0.75 per cent may be rejected. It is assumed in the foregoing discussion that all determinate errors have been eliminated and that only indeterminate errors remain.

The per cent average deviation from the mean (A. D.) is given by the formula:

$$\text{Per cent A.D.} = \frac{(d_1 + d_2 + d_3 + d_n) 100}{AN \sqrt{N}}$$

where A is the average of the values of water-rate obtained from N tests

N is the number of tests

and $d_1 = WR_1 - A$

$d_2 = WR_2 - A$

$d_n = WR_n - A$, etc.

where WR_1, WR_2, WR_n are the values of water-rate obtained on the 1st, 2nd and succeeding tests. The absolute values of d_1, d_2 , and d_n , are used regardless of sign.

Table III shows accuracy data from several water-rate tests on large a-c. turbine-generators. The values in the column headed "Per cent maximum difference between values of water rate obtained from tests at each load" show that practically all individual test results fall within a belt one per cent wide. The values in the column headed "Per cent average deviation from the mean" show that the probably true value of water rate is located within a belt varying in width from 0.5 per cent to 0.25 per cent, depending upon the conditions.

Photographic Observation

This article would not be complete without a description of the method whereby Messrs. Kidder and Hall of the Interborough Rapid Transit Co. of New York measured the electrical output of a turbine-generator by means of portable indicating wattmeters, the observations of which were made with motion picture cameras. The use of a second set of portable indicating wattmeters in parallel with the test wattmeters, and read by observers, gave opportunity to determine the effectiveness of the observers.

The photographic measurement was made by mounting an indicating wattmeter in a vertical position together with a motion picture camera so focused that the scale of the

instrument covered the entire width of the film. The wattmeter was provided with a special pear-shaped target pointer, and was properly balanced for operation with the shaft horizontal. Three such instruments and cameras were employed, one set for each phase. The shutter mechanisms of the cameras were operated in synchronism from a common motor-driven drive shaft. Number counters were so mounted on each instrument that the number appeared on the film,

TABLE III

PER CENT MAXIMUM DIFFERENCE BETWEEN VALUES OF WATER-RATE FOR SEVERAL TESTS AT A GIVEN LOAD, AND PER CENT AVERAGE DEVIATION FROM THE MEAN

Turbine-generator Designation Number	Load Kilowatts	Number of Tests at Each Load	Per Cent Maximum Difference Between Values of Water-rate Obtained from Tests at Each Load	Per Cent Average Deviation from the Mean	Type of Load
10	15,000	8	0.37	±0.09	Steady lighting and power
	20,000	4	0.29	±0.09	
	25,000	8	0.77	±0.12	
	30,000	9	0.87	±0.08	
11	15,000	2	0.65	±0.32	Slightly variable
	20,000	2	0.19	±0.07	
	23,000	2	0.10	±0.04	
	28,000	5	0.90	±0.11	
12	23,000	2	0.49	±0.18	Slightly variable
	28,000	2	0.61	±0.29	
13	15,000	2	1.13	±0.40	Slightly variable
	20,000	2	0.00	±0.00	
	23,000	2	0.70	±0.25	
	28,000	2	0.71	±0.22	
14	10,000	3	0.66	±0.18	Steady lighting and power
	15,000	2	0.90	±0.32	
	20,000	2	0.38	±0.13	
	25,000	4	0.00	±0.00	
	30,000	3	0.00	±0.00	
	35,000	2	0.00	±0.00	
15	10,000	3	0.00	±0.00	More variable
	15,000	4	0.18	±0.04	
	20,000	3	0.00	±0.00	
4	15,000	4	0.53	±0.11	More variable
	20,000	8	1.91	±0.18	
	25,000	4	0.09	±0.02	
	30,000	3	0.00	±0.00	
16	23,000	4	0.21	±0.05	Steady lighting and power
	30,000	4	0.42	±0.15	

thus providing means for identifying all pictures. A watch was photographed on the film at the beginning and at the end of each test to obtain the rate of observation. Suitable illumination was produced from mercury vapor tubes. The entire installation was mounted in the generator room near the machine under test.

The shutter operating mechanism operated the shutters at one-second intervals for short-time duration. For long-time duration, such as one-hour test periods, the fastest practicable rate was about one operation per seven seconds, which was the rate maintained during the water-rate tests.

Readings were obtained from the film after development by projecting the image on a screen through a projector and reading the value shown by the pointer. Readings were easily made to within 0.1 small scale division of the wattmeter scale, which is 0.5 watts.

The instruments were compared by setting up secondary standards at the instrument installation in the generator room. Holding scale values on the secondary standard, photographs were taken of the wattmeter indications. After developing the films, the readings were made from the projected image on the screen, and corrections thus obtained. These corrections were later used to correct the wattmeter readings during test. Comparisons were made of the instruments before and after the test series, and intermediate to these at two-week intervals. A preliminary

TABLE IV

PER CENT AVERAGE DEVIATION FROM THE MEAN OF INDIVIDUAL TESTS FOR EACH LOAD POINT

G. E. 30,000-kw. Turbine-generator, Interborough Rapid Transit Co., New York

Load Kilowatts	Number of Tests	Per Cent Average Deviation from Mean of Individual Tests	
		Photo- graphic Method	Visual Method
14,000	2	±0.79	±0.78
16,000	2	±0.25	±0.21
18,000	2	±0.19	±0.02
20,000	2	±0.34	±0.22
22,000	2	±0.13	±0.09
24,000	3	±0.21	±0.24
26,000	4	±0.22	±0.27
28,000	6	±0.27	±0.28
30,000	4	±0.17	±0.21
Average (omitting 14,000 kw.)		±0.22	±0.20
Average (including all loads)		±0.28	±0.26

heat run was also made, as previously indicated. The comparisons were all made by the Electrical Testing Laboratories, New York.

The wattmeters used in parallel with the test instruments were compared at the same time as the test instruments except that they were read by observers. Observations were made during test following the principles as described herein. Readings were made at 10-second intervals. Tests were of one-hour duration, there being three tests each day for nine days during a period of four weeks. At no time did the observers complain of fatigue.

The Interborough Rapid Transit Company carries a railway load, and the continual variation in it was the reason for employing photographic means for obtaining accurate observations. This load is undoubtedly the most variable of the large commercial loads in this country, and results obtained thereon may be taken as representative of the attainment possible under the worst of conditions as regards variable load.

The performances of the photographic method and the visual method are best shown by Tables IV and V. These show the truly remarkable results that may be obtained on a highly variable load with portable indicating

TABLE V

DIFFERENCE BETWEEN WATER-RATE AS FINALLY ACCEPTED, AND WATER-RATE AS DETERMINED PHOTOGRAPHICALLY AND VISUALLY

G. E. 30,000-kw. Turbine-generator, Interborough Rapid Transit Co., New York

Load Kilowatts	Final Accepted Water-rate Expressed as 100 Per Cent	Water-rate by Photographic Method Expressed as a Percentage of Final Accepted Water-rate	Water-rate by Visual Method, Expressed as a Percentage of Final Accepted Water-rate
14,000	100	100.0	99.8
16,000	100	99.9	99.7
18,000	100	100.05	99.9
20,000	100	100.1	100.05
22,000	100	100.1	100.1
24,000	100	100.05	100.05
26,000	100	100.0	99.95
28,000	100	100.15	99.95
30,000	100	100.1	100.

DIFFERENCES IN PER CENT

	Between Photographic and Visual	Between Photographic and Finally Accepted	Between Visual and Finally Accepted
Maximum...	0.2	0.15	0.3
Minimum...	0.0	0.0	0.0
Average....	0.1	0.07	0.1

wattmeters both as read with cameras and with observers. The equality of the results obtained by the two methods is evident. The art of electrical measurements is indebted to Messrs. Kidder and Hall for their persistent efforts in overcoming the difficulties in the photographic method, and in carrying it through to a successful conclusion.

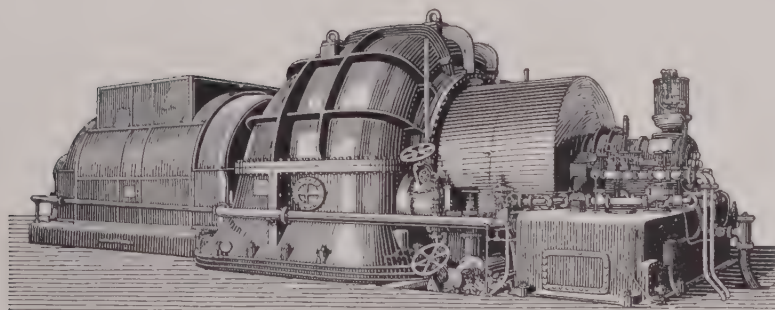
Conclusion

The water-rate of large a-c. turbine-generators can be determined with such accuracy that the per cent average deviation from the mean, as defined, will be within ± 0.25 per cent. This means that practically all individual test results will fall in a belt one per cent wide, while the probably true value of water rate will be located within a belt varying in width from 0.5 per cent to 0.25 per cent, depending upon the conditions. Such re-

sults as these can be obtained on commercial loads, even when the load fluctuations are violent, by using portable indicating wattmeters read by observers following the methods herein described for measuring the electrical output, and with commensurate care in making the steam-input measurements and corrections.

The author wishes to acknowledge the helpful guidance of Mr. L. T. Robinson⁽³⁾ in carrying on with the tests described in this article, as well as the assistance received from Messrs. L. J. Cavannaugh and W. S. Vogel, of the General Engineering Laboratory of the General Electric Company, in conducting the electrical measurements in many of the tests. J. L. Roberts, of the Turbine Department of the General Electric Co., deserves great credit for his contribution to this work, being in charge of the water-rate tests. The effective co-operation of the personnel in the Central Stations where tests were made was also most cordial and helpful, and their contribution to this work is hereby acknowledged.

(3) See papers by Mr. L. T. Robinson as follows:
 "Testing Steam Turbines and Steam Turbine-Generators,"
 E. D. Dickinson and L. T. Robinson. *Transactions A.I.E.E.*,
 1910, Vol. XXIX, part II, page 1679.
 "The Determination of Stray Losses from Input-Output
 Tests," L. T. Robinson. *Transactions A.I.E.E.*, 1913, Vol.
 XXXI, part I, page 531.



Review of Literature on Ultra-violet Therapy

By DR. A. W. HULL

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To most of us, the narrow band of wavelengths in the radiation spectrum known as ultra-violet rays appears to be of little practical value. It is not surprising that electrical engineers, who have perfected the means of producing these radiations artificially, should regard one of their own developments with skepticism when we consider how little publicity has been given to this fascinating subject outside of the medical profession. Nor is it surprising that electrical engineers are so reticent when the subject of ultra-violet radiations is brought up by those who seek authentic information on the efficacy of these radiations, in the treatment of disease, when we realize that practically nothing is said about these rays in textbooks or trade journals. The engineer is thoroughly familiar with Hertzian waves—radio frequency—and is fairly well versed on the subject of x-rays; he has a hazy conception of radio-activity, but in most cases knowledge of ultra-violet rays is very limited. In this article the author discusses, briefly, the common sources of ultra-violet light and presents a survey of the applications of these rays in the treatment of disease.—EDITOR.

Introduction

It was written centuries ago that "light is the life of man." Light is a paramount necessity to the well-being and very existence of human beings. Without light, proper metabolism⁽¹⁾ is impossible; but with light scientifically applied to selected cases, it will do more than any other agent in the service of man to restore normal physiological conditions.⁽²⁾

The pathway leading to the discovery of invisible radiations was opened by Isaac Newton, when he resolved white sunlight into its component colors by passing it through a prism. Ultra-violet radiation was actually discovered a little more than one hundred and twenty years ago. During the interval that has since elapsed, workers have devoted much patient study to the potentialities of this form of energy. In 1877, we find the first important paper prepared on this subject. This was the work of A. Downes and T. P. Blunt, who studied the lethal action of ultra-violet rays on bacteria and showed how they would destroy anthrax bacilli. This paper was published in the Proceedings of the Royal Society for December of that year. In 1901, Peter Cooper Hewitt discovered the mercury vapor lamp, and by producing the arc in a quartz tube he was able to allow the ultra-violet rays to pass through. The natural result of this invention was to give a tremendous impetus to ultra-violet therapy.

Sources

The best known sources of ultra-violet light are the sun's rays; the arcs of carbon, iron, mercury vapor and tungsten; sparks,

especially those between zinc terminals; and the hydrogen glow discharge. The spectral energy distributions of the first four of these sources are shown in Fig. 1. The curves for the various lamps have been reduced to a basis of equal power consumption (400 watts), so that the ordinates of the curves represent relative efficiency, and the areas under the curves, between any given wavelengths, show directly the total efficiency of the particular lamp over this range.

Ultra-violet rays extend, roughly, from 2000 to 3900 Angstrom units.⁽³⁾ The shorter wavelengths, from 2000 to 3000A, are called the "far ultra-violet rays" and constitute the "abiotic" rays, which cannot be tolerated by living beings; while the band of waves from 3000 to 3900A is termed "near ultra-violet" and may be classified as the "sunlight range," since these rays constitute the ultra-violet part of sunlight. Radiations in the abiotic range are lethal to all bacteria and all living tissues, while those in the sunlight range are stimulating to body metabolism, only slightly bactericidal and are tolerated by the body and the eyes. For comparison with these ultra-violet sources, the spectral distribution curve of a Mazda C lamp is given in Fig. 1; also the curve of relative visual sensitivity of the human eye, which extends from approximately 3900 to 7500A.

It is seen that the mercury arc surpasses all other sources in ultra-violet efficiency. Under normal operating conditions (Cooper-Hewitt Uviarc 165 volts, 4.5 amp.) the efficiency of the mercury arc in the ranges 2000 to 3000A, 3000 to 3900A, and 3900 to 7500A is 6, 24, and 50 per cent, respectively, of its total luminous efficiency. Taking Coblentz's⁽⁴⁾ value of 10 per cent for the total luminous efficiency, this means that 0.6, 2.4 and 5 per cent, respectively, of the electrical energy used is transformed into

(1) Metabolism: medical term applied to chemical and tissue changes produced in the human body by the assimilation of food.—Ed.

(2) F. H. Humphris: "Artificial Sunlight and Its Therapeutic Uses," Oxford University Press, September, 1924.

(3) Angstrom Unit, abbreviated A, = a hundred millionth of a centimeter.—Ed.

(4) Coblentz and Kahler: Bur. of Std. Sci. paper, No. 387, April 9, 1920.

light of wavelengths 2000 to 3000A, 3000 to 3900A, and 3900 to 7500A. For comparison with sunlight it may be noted that, under the above operating conditions, the total ultra-violet intensity (wavelengths less than 3900A) of the mercury arc at a distance of 50 cm. is the same as that of average full noon-day sunlight. This does not mean equal therapeutic activity, since the arc is rich in short abiotic wavelengths, while the sun's spectrum ends abruptly at about 2960, due to the absorption of all shorter wavelengths by ozone in the atmosphere.

The mercury arc is also the most steady and reproducible of all these sources. Hence the only present occasion for using other

final operating conditions respectively, and show the relative amount of light of different wavelengths for the same power input under these two conditions. Fig. 3 shows the same variation as a function of current, which increases, with corresponding decrease in voltage across the arc, as the tube gets hotter. It will be noted that there is a great increase in intensity of all wavelengths with increase in temperature (or in current capacity, which is due to temperature); and that some ultra-violet wavelengths increase more than others. The great increase shown in Fig. 2 for long infra-red rays (wavelengths greater than 7500) is due to radiation from the red-hot quartz. Variations of this kind, due

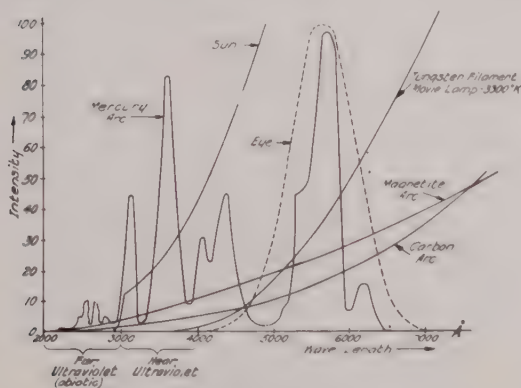


Fig. 1. Curves Showing the Intensity of Various Sources of Ultra-violet Rays at Different Wavelengths

artificial sources is where a continuous spectrum is needed, as for example, in the determination of the exact wavelength limit of bactericidal action. Although the mercury vapor arc is the best available source of ultra-violet radiation, it is far from perfect. It does not maintain constant output either in intensity or in spectral distribution. The amount of light for the same power input doubles as the lamp warms up from starting to normal running temperature⁽⁶⁾; and falls off gradually with length of service, the ultra-violet more than the visible, due to blackening of the quartz.⁽⁶⁾

Variations of the first kind, namely those due to temperature, are shown in Figs. 2 and 3. In Fig. 2, from a paper by Harrison and Forbes,⁽⁶⁾ the lower and upper curves represent approximately the starting and

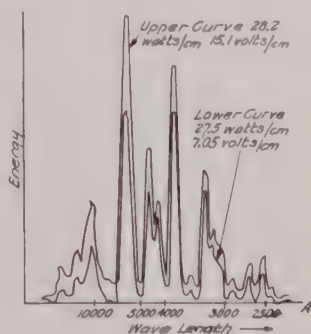


Fig. 2. Energy Distribution of the Spectrum of a Mercury Lamp at Two Different Temperatures

to the temperature of the lamp, are avoided by using the lamp only in its hot condition, after it has been running at least 20 minutes. This does not, of course, hold for two different types of lamp, nor for two of the same type with different degrees of cooling. For example, the 220-volt Uviarc takes 4.5 amp. at 165 volts when operated in open air, but only 3.75 amp. at 174 volts when enclosed in the regular hood mounting.⁽⁷⁾ If due attention is given to these temperature factors, a given lamp can be made to furnish, for a limited time, reproducible intensity and wavelengths.

The decline of efficiency with the life of the lamp, due to the formation on the quartz of a brown deposit which absorbs the ultra-violet rays, is shown in Fig. 4⁽⁶⁾ for two typical commercial lamps. The difference in the rate of blackening of these two lamps illustrates well the variability of this blackening factor. The average rate of blackening shown by these tests was such that the ultra-violet efficiency was

⁽⁶⁾ Harrison and Forbes: *J. Opt. Soc. Amer.*, pp. 1-18, May, 1924.

⁽⁷⁾ Coblenz, Long and Kahler: *Bur. of Std. Sci. paper*, No. 330, November 12, 1918.

⁽⁷⁾ *Cooper-Hewitt Bulletin*, No. 105-A.

reduced to about 50 per cent after 2000 to 3000 hours of operation. The authors of these tests state in a recent paper⁽⁸⁾ that great improvements have been made in the lamps since these tests were made, and that the present rate of blackening is very small. But no up-to-date data are given.

Measurement of Intensity

With present lamps, therefore, the control of dosage by direct measurement is highly desirable, and is necessary if results obtained with different lamps are to be compared. A reliable, but not very accurate, method of comparing any two lamps is to compare the time of exposure necessary to produce a sunburn on the same patient. This time is known as the "erythema dose." Of the many chemical methods of measuring intensity that have been tried, the simplest yet suggested, applicable to abiotic rays, is the darkening of lithophone⁽⁹⁾ paint, which Janet Clark⁽¹⁰⁾ has shown to run very closely parallel to the effect of the ultra-violet rays on bacteria. In other words, the more rapidly the paint darkens the stronger is the bactericidal property of the rays, and in nearly direct ratio.

A still better method, and one which would make possible exact quantitative measurements, is the use of a photo-electric cell. This device utilizes the fact that all metals give up electrons when illuminated by light of appropriate wavelengths, the number of electrons given up being exactly proportional to the intensity of the light. The cell consists of two insulated metal plates in an evacuated tube in which one of the plates can be illuminated by the light to be measured. If the illuminated plate is connected to the negative battery terminal, the other to the positive, a current of electricity proportional to the intensity of the light will flow across the vacuum and through the circuit and battery, and may be measured with a sensitive galvanometer, or, with the aid of amplifying tubes, on an ordinary ammeter. Different metals are sensitive photo-electrically to different wavelengths. For example, of the pure metals only the alkalis, such as sodium and potassium, are sensitive to visible light. Magnesium is sensitive only to wavelengths

shorter than 3500A, copper only to those shorter than 2900A. Furthermore, the sensitivity of each metal increases with decreasing wavelength, in much the same way as bactericidal action. Hence by proper choice of metal a photo-electric cell may be made which will respond to any desired range of wavelengths. It is obvious that the cell must be made of quartz, or of some special glass which is transparent to ultra-violet radiations.

Bactericidal Action^{(8) (11) (12)}

The wavelengths in the abiotic range, as high as 2960A kill bacteria quickly; for example, an exposure of eight seconds, at one

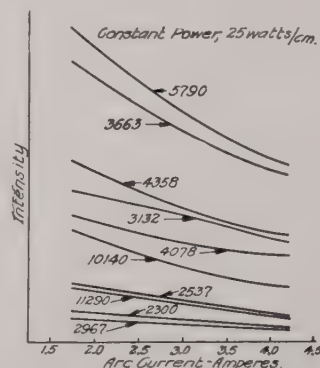


Fig. 3. Variation of Efficiency with Current Flow for Different Wavelengths

foot from a 175-watt mercury lamp, will kill bacillus coli.⁽¹³⁾ The limiting wavelength (2960A) was found by substituting a slide covered with bacterial emulsion for the photographic plate in the quartz spectrograph, using an iron arc as source of ultra-violet light. The limiting wavelength lethal to bacteria coincides with the limit of absorption of the bacterial emulsion, or more exactly the wavelength at which absorption begins to increase very rapidly. The absolute limit of absorption is 3500A, which also coincides with the absolute limit of bactericidal action.

Wavelengths between 2960 and 3500A will kill bacteria only after continued exposure under intense radiations. For example, full sunlight kills staph. aureus in Ph 7.4 agar⁽¹⁴⁾ in three hours, when exposed to sunlight screened by quartz, or by Crookes glass—whose limiting wavelength is 3500A; but when screened by blue glass, which has a lower limit of transmission of 3600A, it fails to kill the same bacteria after six hours exposure. The wavelength limits, 2960A

(8) Coblenz and Fulton, *Bur. of Stds. Sci.*, Paper No. 495, Dec. 10, 1924.

(9) Lithophone: (Heavy Spar) natural barium sulphate.—Ed.

(10) Janet H. Clark: *Am. J. Physiol.* (1924), vol. 69, pp. 200-9.

(11) Browning and Russ: *Proc. Roy. Soc. B*, pp. 33-8 (1919).

(12) Bayne-Jones and Vanderlingen: (Johns Hopkins) *Johns Hopkins Hosp. Bul.*, pp. 11-15 (1923).

(13) Chaviarra and Clark: *Am. J. Hygiene*, p. 639 (1924).

(14) Agar: a non-nitrogenous substance of gelatinous consistency used as a solidifying agent in culture media.—Ed.

for short exposures, 3500A for long exposures, are the same for all bacteria and are independent of the temperature or acidity of the medium.

In a recent paper Coblentz and Fulton⁽⁸⁾ show that colon bacilli can be completely killed by light of wavelengths slightly greater than 3500A, namely, by the strong line of wavelength 3650A from the mercury arc. The exposure required was between 45 minutes and 1 hour, at a distance of 6 inches from a 320-watt lamp. The corresponding exposure for the full light of the lamp at this distance was 1 second, which agrees with the value (8 sec. at 12 in. from a 175-watt lamp) found by Cheviarria and Clark, before quoted. They also found that the "near ultra-

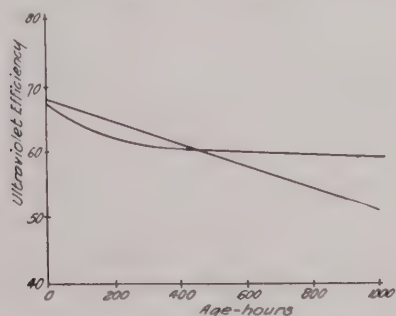


Fig. 4. Variation of Efficiency with the Life of Two Commercial Lamps

violet" part of the mercury arc light; that is, the wavelengths longer than 3000A, was about 1/8 as effective in killing bacillus coli as the "far ultra-violet" part. This agrees very well with the ratio 1/12 found by Hess and Weinstock⁽¹⁵⁾ for the relative antirachitic effect of these two parts of the mercury arc light.

For fungi the wavelength limits are the same as for bacteria⁽¹³⁾ but the exposures required are longer. For eight typical species of fungi the exposure varies from 2 to 55 min. at 1 ft. from a 175-watt mercury lamp. The time required to produce an erythema⁽¹⁶⁾ or reddening of the skin at this distance from the arc was 1.9 min. The exposures necessary to

kill these fungi correspond, therefore, to from 1 to 30 erythema doses.

It is well known that many dyes, of which eosin is one, can sensitize cells so that they react to visible light in the same way that they ordinarily react to ultra-violet. By staining cultures of six of the fungi mentioned with a dilute solution of eosin (1/10 per cent), Chaviarria and Clark increased the wavelength limit of bactericidal action so that these fungi were killed in two hours by winter sunlight through glass (which absorbed practically all the ultra-violet), and an active ringworm (fungus species trichophyton acuminatum) was completely cured in 12 days by exposure to a 200-watt Mazda lamp. A similar unstained ringworm exposed to the same light showed only slight improvement, and a third kept in darkness was unchanged.

Stimulating Action

Of the many stimulating effects ascribed to ultra-violet rays, only one has been definitely proved, namely, the action, which may be due in part to stimulation of the parathyroid glands,^{(17) (18)} which results in normal calcium and phosphorous metabolism and subsequently in the cure of rickets and tetany. Hess and Weinstock⁽¹⁵⁾ fixed the limiting wavelength for this action at about 3500A, the same as the upper limit for bactericidal action. They found that a two-minute exposure daily to full rays of a mercury lamp at 3 ft. would protect animals on a certain diet from rickets. If filtered through 0.8 mm. of pyrex glass, whose limit of transmission is about 3000A, an exposure twelve times as long was required; and if filtered through 4.2 mm. of a special glass whose limiting wavelength was 3500A or 2.6 mm. or window glass, with limiting wavelength of 3340A, an exposure 500 times as great—60 min. daily at 9 in.—failed to prevent rickets. The fact that 0.8 mm. of pyrex increased the necessary exposure twelve-fold indicates that wavelengths below 3000A are more effective stimulators than those above. The ratio of effectiveness of wavelengths longer than 3000A to that of wavelengths less than 3000A would seem to be about the same for stimulating action as for bactericidal action.

Dangers

Verhoeff and Bell⁽¹⁹⁾ conducted a thorough series of experiments on rabbits' eyes, and from these experiments the effects on human eyes may readily be inferred.

⁽¹⁵⁾ Hess and Weinstock: *J. Am. Med. Assoc.*, pp. 687-90 (1923).

⁽¹⁶⁾ Erythema: a local congestion (hyperaemia) accompanied by superficial redness which disappears under slight pressure.—Ed.

⁽¹⁷⁾ Parathyroids: minute glands discovered by Sanstroem in 1890. They are four bodies, each about as large as a pin, embedded in the thyroid gland. Although they are exceedingly small, they exert a powerful influence on the nervous system.—Ed.

⁽¹⁸⁾ Grant and Gates: (Rockefeller Inst.) *J. Gen. Physiol.*, pp. 635-45 (1924).

⁽¹⁹⁾ Verhoeff and Bell: *Am. Ill. Eng. Soc. Proc.*, pp. 625-64 (1921). (See also Rindall, *Chem. Met. Eng.*, p. 1071 (1920).)

An exposure of 6 min. at a distance of 50 cm. to a mercury arc at 90 volts, 3.5 amp., sufficed to produce photophthalmia, consisting of swelling of the eyes and redness of surrounding skin, beginning several hours (but never more than 24) after exposure, subsiding in a few hours, and completely disappearing in less than a week. The wavelengths responsible for this irritation are entirely in the abiotic range ($\lambda < 2960\text{\AA}$) as is obvious from the fact that sunlight ($\lambda > 2950\text{\AA}$) does not produce this effect. An exposure of rabbits' eyes to intense filtered rays of $\lambda < 3050\text{\AA}$ from a magnetite arc, concentrated by a lens to such a degree that it was equivalent to 28 days' continuous exposure to the direct light of the arc at a distance of 1 meter, produced no effect, that is, no visible clouding of the cornea, or redness of the conjunctiva.

For wavelengths in the abiotic range, to which eyes are sensitive, successive exposures within 24 hours were found to be cumulative in their action. Exposures of $1/6$ the limiting value (1 min. at 50 cm.) repeated every 24 hours for 52 days had no effect. Exposures of $1/3$ limiting value every 48 hours could be borne, but if repeated every 24 hours they began to produce a reaction after six exposures.

The injury to the cornea and conjunctiva is superficial and less than 0.02 mm. deep, when directly exposed. No injury is done to parts not directly struck by the light. After severe exposures, up to 150 times the limiting dose, the corneal epithelium⁽²⁰⁾ is reformed in four days, but haziness lasted in the severest cases as long as five weeks. No permanent injury remained. The lens was entirely uninjured by any exposure.

Special attempts were made to detect any injury to the retina. Two monkeys' eyes and one human eye were subjected for $1\frac{1}{2}$ hours to intense rays focused by a lens on the eye, from a magnetite arc. A solution of copper-chloride was used as filter to exclude the infra-red, so as to avoid burning due to heat. This solution did not absorb any of the ultra-violet rays that were capable of getting through the cornea and lens. The result was a temporary blinding, but in all three cases vision was again perfect within 24 hours, and no harmful permanent effects could be found.

In contrast to this temporary effect of ultra-violet, visible and infra-red light from the sun

or electric arc are known to produce serious and permanent injury, due to *thermal* effects on the retina. The lens of the eye acts as a sun-glass, focusing the heat rays upon a point of the retina, which may be destroyed by the intense heat.

Bactericidal Applications

It appears from the literature on this subject that the principal use of the lamps, until very recently at least, has been in the treat-

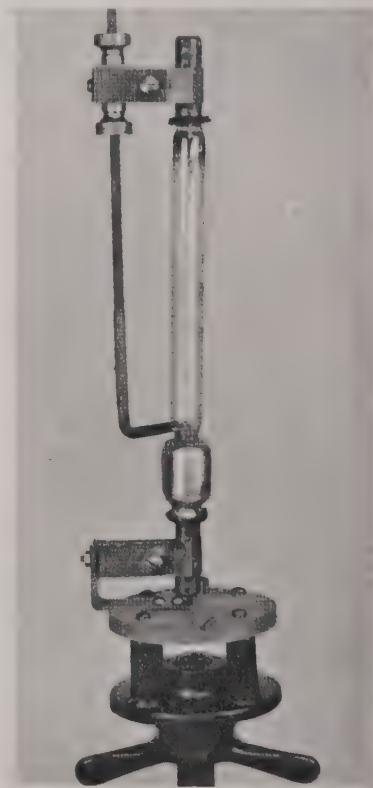


Fig. 5. Vertical Uviarc—220-volt, 1000-watt

ment of skin diseases. In spite of this there is no unanimity among doctors as to its efficacy, not even for a single disease. From reading a number of summaries^{(21) (22) (23)} and discussions one arrives at the following estimate of present practice:

- (1) Lupus Vulgaris—70 to 90 per cent can be cured by ultra-violet, which is admitted to be the best agent.
- (2) Lupus Erythematosus—not over 30 per cent cured, CO₂ snow preferred by many, x-rays by some.

⁽²⁰⁾ Epithelium: the first of the five transparent layers that constitute the cornea.—Ed.

⁽²¹⁾ J. Butler: *U. of Minn. Arch. Derm and Syph.*, pp. 51-72 (1924).

⁽²²⁾ J. W. Jones: (Atlanta) *Southern Med. J.*, pp. 423-6 (1923).

⁽²³⁾ Percy Hall: *J. Royal Sanitary Inst.*, pp. 249-54 (1923-4).

- (3) Acne Vulgaris—x-rays mostly used. A few find ultra-violet just as good, and safer; 75 per cent cures claimed by some.
- (4) Port wine mark, x-ray telangiectasis, surface ulcers: ultra-violet is generally admitted to be of some help; 25 per cent cured.
- (5) Alopecia Areata—50 to 80 per cent of cases reported cured by some.



Fig. 6. Therapeutic Apparatus Using Uviarc Lamps
(Victor X-ray Corporation)

- (6) Parakeratosis Variegata—a few successful cases reported.
- (7) Eczema and half a dozen other skin diseases have very conflicting evidences.

The divergence of opinion is undoubtedly due in part to unintelligent use of the lamp; but much of it probably represents real variation in the resistance of different types of bacteria and spores to light. For example, of the four fungi that are known to cause ringworm, two can be killed by an amount of ultra-violet just

greater than the erythema dose, while the other two require from 3 to 10 erythema doses.⁽¹³⁾ Doses as large as this could probably be tolerated over small areas, though the author has found no experimental data on this point except in the case of eyes. The fact of importance is that accurately measured overdoses of just the right amount have not thus far been used. The ratio of bactericidal to erythema effect probably varies with wavelength, and should be investigated. With more data of this kind available, and careful measurement of dosage, there is reason, from results of reported experiments with bacterial cultures, to hope for eventual 100 per cent success in the treatment of local skin infections. Present practice, however, is far from this goal.

Rickets

A score of researches^{(24) (25) (26)} have thoroughly established the fact that rickets and tetany, the calcium and phosphorus deficiency diseases of young children, can be both cured and prevented by daily sub-erythema treatments with ultra-violet rays. The effective wavelengths are below 3500Å. The part of the mercury arc light which is below 3000Å (limit of 0.8 mm. pyrex) is about 12 times as effective as the part above 3000Å. This means that a mercury arc lamp in pyrex would be 1/12 as effective in curing rickets as the quartz lamp. It would not injure the eyes, and it would have approximately the same bactericidal action as sunlight.

The antirachitic effect of ultra-violet is not different in any respect, either chemically or clinically, from that of substances such as cod-liver oil, which contain the antirachitic vitamin. The application of either of these agents, namely, light and vitamin-containing food, promotes an increased absorption and retention of the calcium and phosphorus eaten, so that the calcium and phosphorus content in the blood approaches normal when only very minute amounts are fed. In the case of such deficient feeding, growth is not quite normal, but vastly better than if no ultra-violet ray or vitamin treatment were given.

Regarding the mechanism of this action, Grant and Gates⁽²⁷⁾ (Rockefeller Institute) submitted evidence to show that it is accomplished, in part at least, through normalized action of the parathyroid glands. It had previously been shown⁽²⁸⁾ that removing the parathyroids from dogs results in greatly increased excretion of calcium and inability to

⁽²⁴⁾ E. Mellanby; *Brit. Med. J.*, p. 895 (1924).

⁽²⁵⁾ Powers, Park, Shipley, McCullom and Simonds; *J. Am. Med. Assoc.*, pp. 159-65 (1922). (Good review of literature).

⁽²⁶⁾ A. F. Hess and Gutman; *J. Am. Med. Assoc.*, p. 39 (1922).

⁽²⁷⁾ J. H. B. Grant and F. L. Gates; (*Rock. Inst.*) *J. Gen. Physiol.*, pp. 635-45 (1924).

⁽²⁸⁾ Salvesen; *J. Biol. Chem.*, p. 635 (1923).

absorb ingested calcium from the intestines. Similarly, diminished absorption and increased excretion of calcium was observed in cases of rickets and tetany,⁽²⁹⁾ which were, therefore, attributed to insufficient parathyroid action. When these cases were rayed with ultra-violet, the absorption of calcium by the intestines, measured by analysis of feces, increased from 0 to 30-50 per cent of the amount ingested. Grant and Gates found that the parathyroids of normal adult rabbits increased 50 per cent in size under ultra-violet treatment. The normal amount of calcium in the blood showed no increase. They concluded that light causes some change in the composition of the blood, to which the parathyroids are sensitive and to which they react by hypertrophy.⁽³⁰⁾ The function of the parathyroids is to maintain the calcium level of the blood constant, at or slightly above

Further evidence regarding the mechanism of this action, which promises information on the relation between light and oil, is contained in the work of Hess and Weinstock⁽³⁴⁾ and Steenbock and Black,⁽³⁵⁾ who find that other oils, such as cottonseed and linseed, and other food substances containing very little antirachitic vitamin, become antirachitic if exposed to ultra-violet rays. Hess further found that any oil containing unsaponifiable material can be thus activated, and that *pure cholesterol*,⁽³⁶⁾ the chief unsaponifiable constituent of vegetable and animal oils, can be thus activated. Hess therefore suggests that, since a large portion of the cholesterol in the body is found in the skin, the antirachitic action of the light consists in activation of this cholesterol, which is then distributed through the blood stream, and acts in identically the same way as the

TABLE I

Wavelength in Angstrom units ..	4360	4050	3660	3540	3130	3020	2970	2890
Per cent transmitted by 0.1 mm. .	59	55	49	42	30	8	2	0.01
Per cent transmitted by 1.0 mm. .	0.5	0.3	0.08	0.02	....	....	....	....

saturation, the excess being probably combined with protein. Larger glands cannot raise the level, but inadequate ones may let it drop.

The nature of the change in blood composition brought about by light is hinted at by Wiener⁽³¹⁾ of Berlin, who finds a large increase in the albumen content, after radiation, and as much as 80 per cent increase in purin excretion. Pincussen⁽³²⁾ also finds a marked increase in albumen metabolism. Tryfus⁽³³⁾ injected blood from rayed guinea pigs into normal unrayed ones, and found a three-fold increase in eosinophile leucocytes after 15 to 30 min., subsiding to below normal in eight hours; whereas blood from unrayed pigs caused a continuous fall in this count for 8 to 12 hours, to very low values. He concludes that light causes an increased metabolism that results in free albumen products, which are toxic, but soon are destroyed.

⁽²⁹⁾ Oer, Holt, Wilkins and Boone: *Am. J. Dis. Child*, p. 362 (1923).

⁽³⁰⁾ Hypertrophy: Abnormal or disproportionate enlargement.—Ed.

⁽³¹⁾ H. Wiener: (Berlin) *Klin. Wochenschr.*, p. 937 (1924).

⁽³²⁾ L. Pincussen: *Strahlentherapie*, pp. 625-54 (1924).

⁽³³⁾ E. Tryfus: *Klin. Wochenschr.*, pp. 694-5 (1923).

⁽³⁴⁾ Hess and Weinstock: *J. Am. Med. Assoc.*, p. 1845 (1924).

⁽³⁵⁾ Steenbock and Black: *Science*, September 5, 1924; *J. Biol. Chem.*, p. 405 (1924).

⁽³⁶⁾ Cholesterol: a white, fatty crystalline alcohol, tasteless and odorless, found in numerous animal products and tissues and especially in nerve tissue.—Ed.

⁽³⁷⁾ *Deutsche Med. Wochenschr.*, p. 1157 (1923).

⁽³⁸⁾ E. M. Luce: *Chem. and Industry*, March, 1924.

similar substances absorbed into the blood through the intestinal walls when cod-liver oil is fed.

Other Stimulating Uses

A few cases of treatment of whooping cough with ultra-violet have been reported.⁽³⁷⁾ In every case spasms and vomiting stopped after three treatments with the "alpine sun" mercury lamp on the breast and back, administered every other day. In no case was there any cure. The cold simply ran its ordinary course, but without severe spasms.

Relief of symptoms in tuberculosis of the bone and intestines has been reported by Dr. H. J. Howk and others. It is too early for conclusions, but the fact that healing in this disease normally proceeds by segregation of infected areas by calcified walls gives theoretical ground for optimism.

Reports of a fourfold increase in egg production by hens rayed 10 min. daily with ultra-violet (12 rayed pullets, 12 unrayed) must be looked on with skepticism until further control experiments have been made. The effect of the light, if real, must be upon some substance (cholesterol) in the feathers or comb, which then finds its way into the blood circulation. The same applies to the reported increase in antirachitic value of cows' milk in summer,⁽³⁸⁾ though in this

case the nature of the food is probably of importance.

There is some evidence that ultra-violet stimulates the general protective mechanism of the body. Hanawa⁽³⁹⁾ found that pigmented skin is more sensitive to irritants, such as Croton oil, CO₂ snow, and iodine, than unpigmented skin. This he attributed to absence (because of absorption by the pigment) of the stimulating effect of normal sunlight. He found, similarly, that the white areas on speckled animals heal faster from wounds and infections than the dark areas. Meyer⁽⁴⁰⁾ found that vitiliginous spots were less sensitive, judged by reddening, to irritants such as turpentine, after ultra-violet radiation than similar unrayed spots, and less sensitive than surrounding pigmented areas which had received the same radiation. This protective action of light is probably to be correlated with its irritant effect, which results in an increase of the red corpuscles and haemoglobin content of blood. With repeated exposures⁽⁴¹⁾ the erythrocytosis⁽⁴²⁾ becomes less and less, and is imperceptible, for the same exposure, after full pigmentation. It is concluded that the function of pigment is purely protective, to adjust the tolerance of the skin to its environment. There seems to be no adequate foundation for the belief that pigmentation is a sign of therapeutic benefit.

In interpreting the results of skin radiation, the depth of penetration is an important factor. The classic measurements of Glitscher and Hasselbach on skin absorption are given in Table I. It is to be noted that the longest useful ultra-violet rays ($\lambda = 3540\text{\AA}$) are reduced to less than half intensity in penetrating 0.1 mm. into the skin, and to 0.02 per cent at a depth of 1 mm.; while the longest abiotic rays ($\lambda = 2890\text{\AA}$) are reduced to 0.01 per cent in 0.1 mm. These measurements

apply to normal skin with its quota of organic and inorganic materials. It is possible that dead surface scales have a much greater transparency than that given in the table.

The maximum tolerance of skin for visible rays is given by Butler⁽²¹⁾ as 3.71 cal. per cm.², of which 35 per cent is reflected, for 1 minute. This results in a surface temperature of 43.8 deg. C., falling to 40.8 deg. C. in 15 seconds. The tolerance for infra-red is slightly less, namely, 1.79 cal. per cm.² for 1 minute of near infra-red, and 1.35 for far infra-red (no reflection), resulting in a surface temperature of 45.5 deg. C.

Conclusion

The mercury vapor arc is the most efficient and reliable source of ultra-violet light at present available, but its variation with temperature and age makes direct measurement of intensity of the light imperative. No satisfactory method of measuring intensity is in use. The photo-electric cell offers the best promise for this purpose.

The therapeutic value of ultra-violet light is unquestioned in one field, namely, the cure of rickets and tetany. In this field the effect of the light, whether from sun or arc, is identical with that of cod-liver oil and similar "antirachitic" foods. This remarkable coincidence has been shown to the intimately connected with the photo-chemical action of ultra-violet light on cholesterol, a constituent of the blood lymph; but the nature of the antirachitic substance is still unknown.

In other fields the value of ultra-violet therapy is still in doubt. There is ground for hope that with better standardization of lamps and better understanding of the bactericidal and stimulating action of the light this doubt may soon be banished. The greatest need is for laboratory experiments, which will serve both as a guide to clinical practice, and as a basis for the interpretation of clinical results.

(39) Hanawa: *Dermatol Zs.*, (1913).

(40) P. S. Meyer: (Univ. of Breslau) *Archiv. fur Derm. und Syph.*, p. 238 (1924).

(41) Burchard: *Strahlentherapie* (1921).

(42) Erythrocytosis: the formation of red blood corpuscles. —Ed.



Determination of the Reactive Kv-a. and the Capacity Necessary to Improve Power-factor

By J. HAK

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The nomogram here described offers a labor-saving tool with which many engineering calculations may be shortened and the tedious work of repeated slide-rule calculations avoided. The following article, which is a translation by Mr. A. R. Stevenson, Jr., is taken from *La Revue Generale de L'Electricité*.—EDITOR.

Introduction

The equations relating to the improvement of power-factor contain trigonometric functions, and it is easiest to represent these equations by plotting them as curves. Although the methods of graphical representation are all very similar, one finds, among different authors, almost always two distinct sets of curves, one for the determination of the reactive kv-a. necessary to give the desired correction, the other for the determination of the capacity of the static condenser or synchronous condenser corresponding to this reactive kv-a. These curve sheets usually contain a family of curves which are not very easy to read, and between which it is necessary to interpolate. They give, as a rule, only the ratio of the respective values of the kw. and reactive kv-a., so that a supplementary calculation by means of a slide rule is usually necessary.

However, it is possible to arrange the equations in a nomogram, containing one system of auxiliary straight lines. This nomogram, being of simple construction, gives directly all the desired values necessary for power-factor computation, and avoids any additional slide-rule multiplications.

Equations to be Solved

Let P represent the real power in kilowatts, and S the reactive kv-a. required to correct the power-factor from an initial value; $\cos \phi_1$, to a desired value $\cos \phi_2$. Then the relation between these variables will be

$$S = P (\tan \phi_1 - \tan \phi_2). \quad (1)$$

Again, let E be the effective potential difference in volts at the terminals of the condenser; F the frequency, and C the capacity of the condenser in microfarads. These three variables will then be related to the value S by the relation

$$C = \frac{S}{2 \pi F E^2} 10^9 \quad (2)$$

In addition to these fundamental equations, one other can be written giving the

percentage reduction in current obtained by power-factor correction,

$$k = 100 \left(\frac{1 - \cos \phi_1}{\cos \phi_2} \right) \quad (3)$$

Construction of the Chart

The nomogram shown in Fig. 1 represents the two equations (1) and (2), and contains, at the left, two scales for $\cos \phi_1$ and $\cos \phi_2$, the linear graduation of which corresponds to $\tan \phi$. Lines drawn through two points, respectively, on the scales for $\cos \phi_1$ and $\cos \phi_2$ intersect the auxiliary line A , and cut off upon it a distance proportional to $(\tan \phi_1 - \tan \phi_2)$. The second auxiliary line B has a logarithmic graduation, and is connected to line A by a series of auxiliary lines joining points of the same value on the linear scale A with the corresponding logarithmic scale B . With the aid of these auxiliary lines the intercepts on A may be readily transferred to B by constructing lines parallel to them or by interpolating by eye.

It is then possible to use the contiguous logarithmic scales for P and S in such a way that a straight line passing through any three points whatever on the scales P , S and B shall represent equation (1) expressed in logarithms,

$$\log S = \log P + \log (\tan \phi_1 - \tan \phi_2)$$

Equation (2) is no more than a simple multiplication. It is easy to represent it by an ordinary nomogram containing logarithmic scales for S , F , E and C , the first being identical with that which was used in the nomographic representation of equation (1).

Finally, equation (3) is separately represented by a simple nomogram (Fig. 2) containing the three scales for $\cos \phi_1$, $\cos \phi_2$, and k , graduated logarithmically, corresponding to $\log \cos \phi_1$, $\log \cos \phi_2$ and $\log \left(1 - \frac{k}{100} \right)$.

Use of the Nomogram

With the aid of these two nomograms, it is possible to solve all of the problems

connected with the improvement of power-factor. Some examples of the application of the Charts follow:

Example 1. Given the power in kilowatts, P , what is the reactive kv-a., S , necessary to correct the power-factor from an initial value $\cos \phi_1$ to a desired value $\cos \phi_2$?

Solution: From the intersection on the auxiliary line A of a line drawn through the points corresponding to $\cos \phi_1$ and $\cos \phi_2$, draw a line between A and B as indicated.

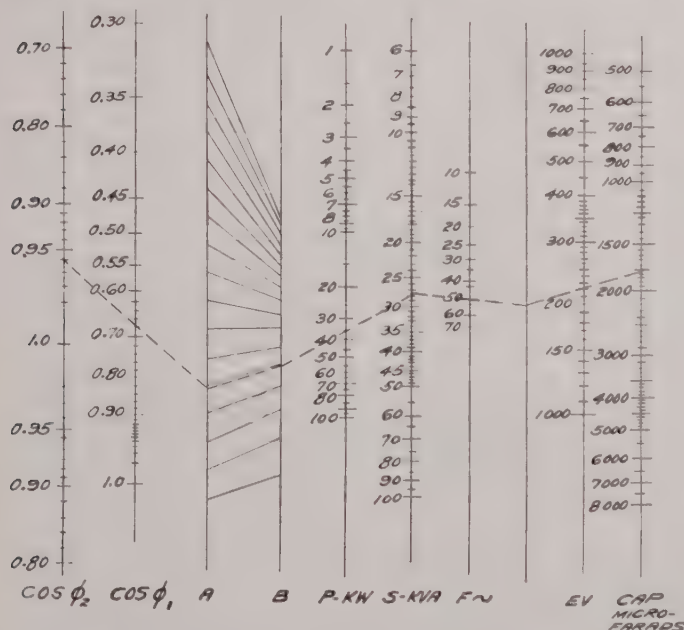


Fig. 1. Nomogram for the Solution of Power-factor Equations

Relating initial and desired power-factor, kw., reactive kv-a., voltage, frequency and capacity

The line joining the point of intersection on B with the point corresponding to P on the kw.-scale intersects the scale for S at the desired value of reactive kv-a.

Example 2. What is the capacity C corresponding to are active kv-a., S , at a voltage E and a frequency F ?

Solution: The line joining the points S and F intersects the blank auxiliary line, as shown in the Fig. 1. A straight line through this point of intersection and the point corresponding to E on the voltage scale, intersects the scale C at the desired value of capacity in microfarads.

Example 3. What is the percentage reduction in current obtained by improving the power-factor from an initial value of $\cos \phi_1$ to a desired value $\cos \phi_2$?

Solution: A line drawn as in Fig. 2, through the points corresponding to $\cos \phi_1$ and $\cos \phi_2$, by its intersection on scale k will give the percentage decrease in current.

Example 4. Given a real power of P kw., a potential of E volts, and a frequency of F cycles per second. To what value can an initial value $\cos \phi_1$ be raised by the addition of a capacity of C microfarads?

Solution: Passing successively through the points corresponding to the given values

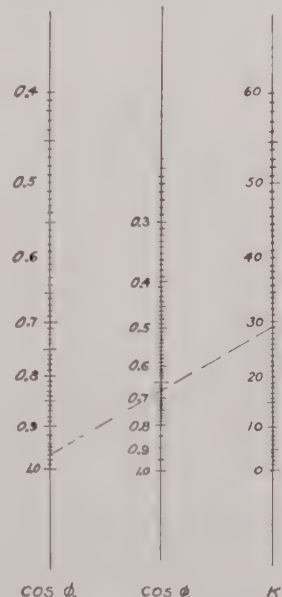


Fig. 2. Current Decrease Due to Improved Power-factor

Intercept on scale k gives per cent reduction in current

of C , E , F , P , and of $\cos \phi_1$, the desired value of $\cos \phi_2$ is found.

Numerical Application—The dotted lines on the nomograms correspond to the following numerical values:

$$\cos \phi_1 = 0.68 \quad \cos \phi_2 = 0.96 \quad P = 35 \text{ kw.}$$

These give $S = 27.5$ kv-a.

And for $F = 50$ cycles per sec.
 $E = 220$ volts

it is found that the required capacity is

$$C = 1810 \text{ mf.}$$

On the nomogram (Fig. 2), for the percentage reduction in current k , and for these values of $\cos \phi_1$ and $\cos \phi_2$, it is found that

$$k = 29 \text{ per cent.}$$

The Technique of Examining Metals Under the Microscope

PART II: ETCHING

By GUSTAV PIRK

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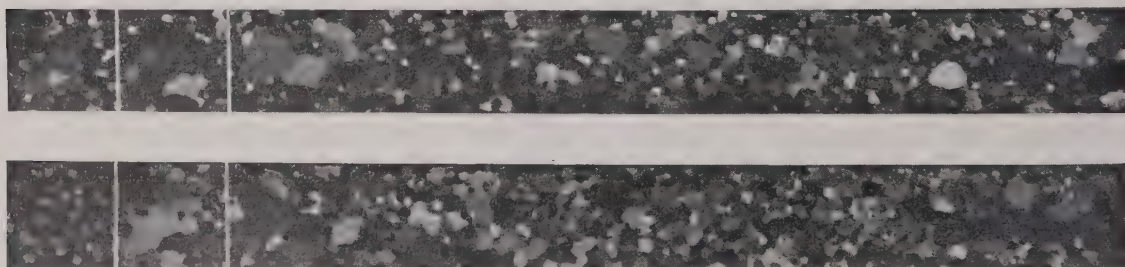
This is the second of a series of articles by Mr. Pirk on the preparation of metals for microscopic examination. The author lists, in this installment, the best known etching reagents for metals and their alloys. In an early issue of the REVIEW we will print the concluding article of this series in which the author will discuss the optics of the microscope and efficient methods for recording the results of these examinations.—EDITOR.

The previous article has dealt with the most important step in the preparation of a metallic specimen for microscopic analysis, namely, that of polishing. The necessity for certain precautions in the polishing process has been fully discussed. Some mention has also been made of the mechanism of polishing and the things which may be observed on a polished surface. If an examination is to be of any scientific value we must treat the surface with a chemical reagent which will dissolve the layer of amorphous metal which has been

fine structure of the metal and bring out detail.

The activity of an etching reagent is dependent upon its degree of ionization; the lower the percentage of ionization, the lower the activity.

The nature of the solvent affects the degree of ionization to a very marked extent. Most substances have their greatest ionization in water. The ionization decreases as the viscosity of the solvent increases. Picric acid, for example, has a very slow but decided



Figs. 7a and 7b. Two Photographs of a Piece of Etched Silicon Steel Illuminated at Different Angles. Note the different appearance of the two portions included in the white lines

formed on the surface during polishing, in order to reveal the true structure of the metal. This process of chemical attack is known as etching.

The Nature of Etching

Etching is primarily a differential chemical attack on the various constituents which are present in a metallic aggregate. The value of a good etching reagent lies in the fact that it will develop the structure as it actually exists. The action of the etching reagent must not be too drastic or the contrast between the various constituents will be destroyed. The degree of activity can be controlled by using solutions of various concentrations. It is a very rare occurrence to employ a concentrated etching reagent where it is desirable to develop the

etching effect when dissolved in substances of a high viscosity, such as glycerine and amyl alcohol. Since too slow a rate of etching is rather inconvenient, most etching reagents are either dissolved in water or ethyl alcohol.

The structure of a metal as it is seen under the microscope is dependent upon the chemical composition of the metal. A pure metal presents a polygonal structure. Although the metal is quite pure, the surface will not be uniformly attacked by the etching reagent. Because of the random orientation of the crystals of a metallic aggregate, various faces of the crystals are exposed to the etchant and some are more rapidly attacked than others. The result is that there will be a difference in level between the crystals, the boundaries between the crystals showing up

as dark lines. If the etching be continued for some time, little valleys will develop at the grain boundaries. This is due to the fact that the metal at the grain boundaries dissolves more rapidly than that on the crystal faces.

The etching reagent also roughens the surface of the crystals, and in the case of copper, a surface film of oxide is produced. As a result of this action some of the crystals will appear light and others dark. The crystals which reflect the light to the eye will appear bright while those which reflect the light in such a direction that the light waves do not strike the eye will appear dark. This is illustrated in Fig. 7a and 7b.

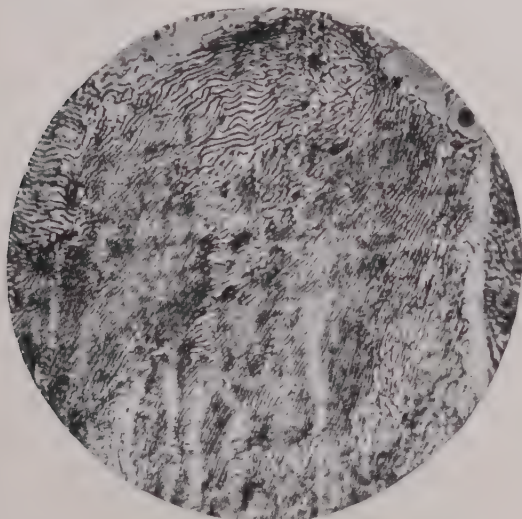


Fig. 8a. Eutectic in White Cast Iron. Lamellar Pearlite Etched with Saturated Solution of Picric Acid in Ethyl Alcohol, 600 Magnifications

If the metal is composed of two or more elements which form a compound or produce a structure different from that of the pure metal, it may be identified by the peculiar structure exhibited. Very often the constituents of an alloy will be stained a characteristic color. This then affords a means of recognizing the elements in alloys. Fig. 8 illustrates this point. In Fig. 8a we have the characteristic pearlitic structure in cast iron, the small spherical particles being the compound Fe_3C or iron carbide. Fig. 8b shows a piece of quenched high-carbon steel. The dark acicular constituent is Martensite.

Cleaning the Specimen

In order that a satisfactory etch may be obtained there is a definite line of procedure which must be followed. The first requisite is,

of course, a well polished surface. Before the specimen is exposed to the action of the etching reagent, the surface must be thoroughly cleaned and freed from all traces of dirt and grease. If there is any grease on the surface the etching reagent will not attack it uniformly and the result will be a very poor etch.

In order that a clean surface may be obtained, the specimen should be washed by holding it under running water and then swabbing the surface with absorbent cotton which has been saturated with 95 per cent alcohol solution. The commercial denatured alcohol should not be employed as it may corrode the sample.



Fig. 8b. Quenched 1.8 Per Cent Carbon Steel, Showing Martensitic Structure, Illustrating Constituents of Two Different Colors, 1200 Magnifications

Chemical Etching

The specimen, after being cleaned, is ready for the process of etching. A very satisfactory way of performing the etching operation is described here. The materials needed are three glass dishes with covers, a piece of clean blotting paper and a sheet of Japanese rice paper. Dish No. 1 should contain the etching solution, dish No. 2 plain water, and dish No. 3, 95 per cent ethyl alcohol. The sample is first immersed in the etching solution, and should be kept in motion while being etched. This movement will cause the etchant to be agitated and will always keep a fresh portion of the reagent in contact with the surfaces of the sample. Gas bubbles and surface deposits will also be removed by this action, thus exposing the whole surface and making a uniform etch possible.

After the sample has been etched the proper amount, it should be immediately immersed in the dish containing water, and the etchant thoroughly washed off. As much of the water as is possible should be shaken from the specimen. The next step is to immerse it in the 95 per cent alcohol solution and swab the surface with absorbent cotton which is saturated with the alcohol.

To dry the specimen it is lightly pressed against the blotting paper over which the rice paper has been placed. The blotting paper absorbs the moisture and the rice paper removes any trace of foreign material adhering to the surface. A blast of clean, dry air may also be used for drying the specimen.

Electrolytic Etching

There are three other methods of etching which are used to some extent, namely: polish attack, heat tinting, and electrolytic etching. The last method is very well adapted to the etching of tungsten, copper-nickel alloys, copper-tin alloys and Monel metal.

Some suitable electrolyte, usually a neutral salt, is added to water, the specimen being made the anode and a piece of platinum or tungsten foil the cathode. A low density current is employed, approximately 0.1 amp. The current density, however, is determined by the kind of etch that is required, a low current density being used for light etching and a higher density for a deep etch. Best results are obtained by using a deep or heavy etch for a fraction of a second at first. This will remove the layer of amorphous metal which has been produced by the polishing process. This is followed by a light etch for a longer period, the time being determined by experiment, as it varies for the different metals and alloys. A longer etch at a low current density brings out the fine structure and develops the detail of the specimen.

Electrolytic etching has much to recommend it. If a neutral salt is used it will be found unnecessary to change the etchant for the heavy and light treatments, but merely to vary the current density, in order to develop the structure of the various metals and alloys.

By varying the current density the process is at all times under the control of the operator and can be halted at once by merely breaking the circuit. In the case of a chemical etching reagent the action will continue even after the specimen is removed from the solution as some of the reagent will always adhere to the surface and attack it.

There are undoubtedly many other points which make the electrolytic method a very useful tool, but the fact that by using a suitable electrolyte and controlling the current density it is very easy to etch such metals as tungsten and Monel metal, which are very resistant to chemical attack, makes this method the most universal etching process.

Heat Tinting

This process is not, strictly speaking, one of etching. Nevertheless, it is very useful in distinguishing the phosphide from the carbide in steel. The phosphide will darken more readily than the carbide and the surrounding metal.

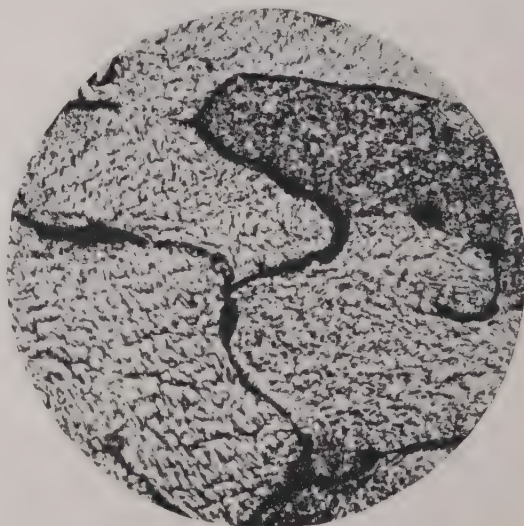


Fig. 9. Effect of Over-etching Tungsten with Boiling Solution of Three Per Cent H_2O_2 , 600 Magnifications

Heat tinting may also be used to distinguish the free carbide from the phosphide segregation in white cast iron where the free carbide will darken more than the phosphide. The compound Cu_3P and Cu_4Sn or δ which occur in bronzes may also be distinguished by this method. The phosphide will turn a beautiful blue while the Cu_4Sn turns yellow.

The process is carried out by heating the specimen to a temperature of approximately 300 deg. C. in air until the surface assumes a reddish brown color. It is not necessary that the process be carried out in the air as atmospheres of hydrogen sulphide and bromine may also be used to good advantage. If an atmosphere other than air be used, the film will not be a colored oxide but one of sulphide or bromide of the metal.

The process depends on the differential oxidation rates of the constituents concerned, thus producing films of varying thickness and the coloring effect noted.

To obtain best results it is of paramount importance that the surface be absolutely free from grease and dirt or the result will be a very uneven etch. Weird figures have sometimes been developed by a trace of grease.

The layer of amorphous metal which is on the surface should first be removed by a slight etch with a dilute hydrochloric acid (1 per cent solution). Picric acid may also be used as a 1 per cent solution in ethyl alcohol. Picric acid is preferable to hydrochloric acid and should be applied by lightly rubbing the

the polishing cloth. The method is a double edged tool and unless it is in the hands of an expert it is very difficult to produce uniform results. It is very easy to smear the surface or scratch it. Hudson describes the process as follows: "The parchment is thoroughly moistened with water and then spread on a smooth wooden support. Three or four drops of dilute ammonia (1 part strong ammonia to 1 part water) are sprinkled on the parchment, together with a little freshly ignited magnesium carbonate. The specimen is then rubbed gently but steadily, usually with a circular motion, on the parchment for a short time (15 seconds), washed thoroughly, dried quickly on an old clean linen, and examined. If necessary, the operation is repeated. By varying the amounts of ammonia and magnesium, and the strength of the rubbing, the crystals can be darkened to different degrees or the structure may be seen quite unstained and thoroughly outlined."

Desirable Degree of Etch

There is one rule which applies to all methods of etching for microscopic examination and that is, for a high-power examination a light etch should be used, while for low power a medium or heavy etch is best employed. It is common practice to etch lightly at first and make the high-power examination and then etch deeper for the low-power work. It is not necessary that this schedule be followed. The examination may be conducted in the opposite manner making the lower power examination first and then the high power. This usually necessitates the repolishing of the sample as the etch for the low-power work roughens the surface to such an extent that it is extremely difficult to bring all the chief characteristics of the structure into the proper forms for more minute examination.

Nothing has been said regarding the time of etching. The best strength of solution is that which will usually take several minutes to develop the structure. This makes the etching rather slow but not inconveniently so and places it under the control of the operator.

Preserving the Sample

Usually the sample is examined immediately after etching. If it is exposed to the atmosphere for any length of time it will become corroded. To avoid this in cases where it is not possible to perform the examination immediately, the sample is placed in a dessicator until it is wanted. Often

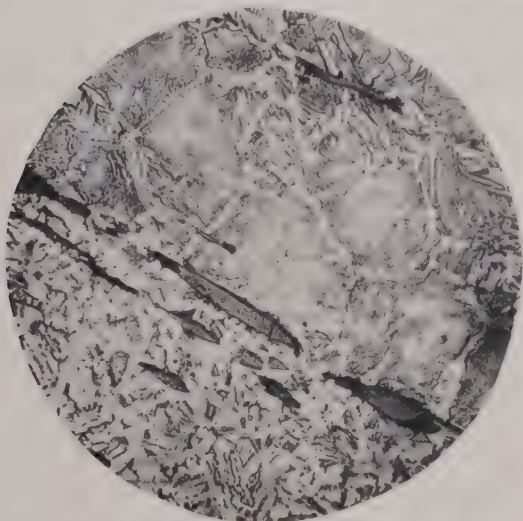


Fig. 10. Alloy Steel, Showing Non-uniform Structure and the Effect of Slag Inclusions on the Microstructure, 200 Magnifications

surface with absorbent cotton or a piece of linen. The sample should then be heated to 150 deg. C. for a few minutes to dry off the moisture.

After heating the specimen to produce the etching, the sample should be quenched in mercury. It is also desirable to look at the specimen at various intervals to see how the etching has progressed, using the mercury quench in each case.

Polish Attack

This method of etching consists in rubbing the surface of the specimen on parchment moistened with an etching reagent. Osmond, who devised the method, used licorice extract and a 2 per cent solution of ammonium nitrate with precipitated calcium sulphate to moisten

it is necessary and desirable to preserve the etched surface for some time. In this case the surface is coated with collodion dissolved in amyl alcohol or celluloid in acetone. The solution is gently brushed on the surface and the specimen is set aside to dry, leaving a thin coating which will not interfere with subsequent examination. Samples of steel may be made passive by immersing them in Cr_2O_3 acid.

Recently, a very satisfactory method has been developed by L. V. Foster.⁽¹⁾ The method consists of preparing a transparent replica of the polished and etched surface. The specimen which has been freshly etched is coated with a thin layer of collodion, which is stripped from the surface when dry. This is mounted on a glass slide and protected by the usual type of cover glass. This celluloid strip or replica has imprinted on it the exact structure and detail of the original sample. It can be examined by using either transparent bright field illumination or dark field illumination. The latter produces negative representation.

This method makes it very simple to file away the complete structure of any sample without having a large array of bulky cabinets for the storage of specimens.

Etching Reagents

It is impossible to list all of the etching reagents which are in use at the present time. Only the most useful ones will be discussed here. Because of the industrial importance of iron and steel, the etching reagents for these metals will be treated separately.

A. Iron and Steel Reagents

Nitric Acid— HNO_3 .

The concentrated acid is seldom used. Sauveur recommends immersing the sample in concentrated nitric acid, which makes it passive, and then spraying water on the surface. The dilute acid which is thus formed etches the surface and develops the structure. Concentrated nitric acid has been used to develop the structure of slag inclusions in iron alloys.

Dilute Nitric Acid

Nitric acid forms oxides on the surfaces of metals which may be either soluble or insoluble. If they are soluble the acid will dissolve them, thus exposing the surface to further action. If the oxidizing action pro-

ceeds at a greater rate than the solution rate the surface will be covered with an oxide. This is an undesirable feature and should be avoided. Tin develops a heavy coating of oxide when treated with nitric acid.

Nitric acid is used in strengths varying from 1 to 5 per cent in either distilled water or ethyl alcohol. This solution is used to etch wrought iron, annealed and heat-treated steel and cast iron. For nickel and manganese steel a 10 per cent solution of nitric acid is used. This strength of solution will develop the grain size very well. Courbatoff recommends a 4 per cent solution of nitric acid in iso-amyl alcohol for etching both quenched and tempered steel.

Nitric acid solutions are used extensively in commercial work. Their action is too drastic, and the surface becomes badly pitted unless great care is taken. This reagent is satisfactory for low-power examination only. The oxide and slag inclusions are attacked by it, thus making it useful as an indicator of the "condition" of the steel.

Picric Acid

This is the most widely used etching reagent for developing the micro-structure of iron and steel. The activity of this acid can be easily controlled by using various solvents bearing in mind that the activity decreases as the ionization decreases. The following series of solvents is arranged in a descending order of activity: water, methyl alcohol, ethyl alcohol, glycerine, propyl alcohol, amyl and iso-amyl alcohol. The following solutions are usually employed.

- (1) Picric acid 4 grams, ethyl alcohol 100 cc.
- (2) Saturated solution of picric acid in ethyl alcohol.
- (3) Picric acid 4 grams, iso-amyl alcohol 100 cc.

Solutions (1) and (2) are the most active of the group and are used to etch quenched steels. The sample is allowed to remain in the solution until the surface becomes brown and green in reflected light. This reagent is not very well adapted to the etching of special alloy steels which require an oxidizing agent such as nitric, chromic, or sulphuric acid, or aqua regia.

The author finds that the addition of a few drops of concentrated hydrochloric acid to 20 cc. of saturated solution of picric acid in ethyl alcohol is very serviceable for etching both annealed and quenched tungsten and vanadium tool steels.

⁽¹⁾ L. V. Foster, *Trans. Am. Soc. Steel Treating*, Vol. 5, April, 1924, No. 4, pages 413-419.

Hydrochloric Acid

Hydrochloric acid etches quite differentially, dissolving one constituent more than the other, thus leaving one standing somewhat in relief. Hanemann recommends a solution of the following proportions for both annealed and heat-treated steels.

For etching ordinary steel, a solution of 1 cc. HCl (1.19) in 100 cc. absolute ethyl alcohol. For nickel, chromium, and the special steels he suggests that a 5 per cent solution of picric acid be added to accelerate the action.

Sodium Picrate

This is used for the determination of iron carbide and cementite in steel. This reagent will attack only the large or "massive" particles of cementite. The cementite stands out as black crystals on a light background of ferrite and pearlite. Hoyt finds this reagent useful for etching ferrite plus martensite in quenched medium-carbon steels. The etching requires several hours and brings out the martensite by coloring it dark brown and bringing out its characteristic structure.

The solution is made as follows:

Picric acid, $C_6H_2(NO_2)_3 OH$	2 grams
Sodium Hydroxide, NaOH	24.5 grams
Water, H_2O	73.5 cc.

The picric acid is added slowly while stirring to prevent the precipitation of sodium picrate crystals. The mixture should always react alkaline to litmus paper.

The solution is boiled for 5 to 10 min. with the specimen, after which the cementite will be colored black. The iron tungstide, Fe_2W , and iron tungsten carbide, Fe_2W_2C , in tungsten steels are also attacked, while tungsten carbide, WC, is not attacked.

Neutral Sodium Picrate

Sodium picrate solution, $C_6H_2(NO_2)_3 Na$, is used to distinguish between iron phosphide and cementite. The phosphide will be darkened while the cementite will be left unattacked. This solution is used boiling for about 20 min.

Kourbatoff's Reagents.

The following etching reagents have been used by Kourbatoff to determine troostite and sorbite in steel:

Reagent C. 1 part of 4 per cent solution of nitric acid in acetic anhydride, 1 part methyl alcohol, 1 part ethyl alcohol, and 1 part iso-amyl alcohol.

Reagent D. 2 parts saturated solution of nitro-phenol and 2 parts of a 4 per cent solution of nitric acid in alcohol.

These reagents will color first the troostite and then the sorbite.

Reagent B. This reagent is suggested for hardened steel:

4 parts hydrochloric acid.
20 parts iso-amyl alcohol.
75 parts of nitro-aniline or of nitro-phenol in alcohol.

Tincture of Iodine

This reagent is used to determine segregation, etc., in structural and commercial shapes, especially for microscopic examination. The tincture obtained at the drug-gists or a solution of 1 gram of iodine in 20 cc. of ethyl alcohol may be used. The bottle should be well stoppered and kept in a dark place.

Iodine—Iodide Reagent

Stead recommends a reagent of the following composition for developing the general structure of iron and steel:

Iodine	1.25 grams
Potassium iodide	1.25 grams
Water	1.25 cc.
Ethyl alcohol to make	100 cc.

Complex Cupric Reagents

The cupric reagents are exceedingly valuable for the determination of phosphorus which is dissolved in iron. The areas free from phosphorus are attacked more than those containing phosphorus.

Stead recommends the following reagent:

Cupric chloride	10 grams
Magnesium chloride	40 grams
Hydrochloric acid	20 cc.
Alcohol to make up to	1000 cc.

The salts are dissolved in the least possible quantity of water. The specimen is covered with a layer of the etchant and allowed to stand for about a minute, after which another layer is added. This process is continued until the specimen is properly etched.

Rosenhain and Haughton have also developed a similar reagent which works well. They recommend the following composition:

Ferric chloride	30.0 grams
Hydrochloric acid (conc.)	100.0 cc.
Cupric chloride	10.0 grams
Stannous chloride	0.5 grams
Water	1000 cc.

Heyn's Cupric Reagent

Copper ammonium chloride which was introduced by Heyn is chiefly used to develop the microstructure of low-carbon steels, with special reference to phosphorus segregations. It may also be used on wrought iron and white cast iron.

The solution is as follows:

Water	120 cc.
Copper Ammonium chloride	10 grams

To etch the sample it is covered with the solution and allowed to act one minute. As copper is deposited on the surface the specimen should be kept in constant movement so as to insure uniformity. The copper deposit can be wiped off with cotton under running water. The specimen is then dried with alcohol. In high-carbon steels any phosphorus which is present will be colored brown by this reagent, while the constituents rich in carbon will be turned a pure gray to black.

This reagent is not suitable on gray cast iron, quenched and special alloy steels, as the copper adheres too firmly.

Mercuric Chloride

This solution is made by dissolving 10 grams mercuric chloride in 20 cc. hydrochloric acid. (1.12) in 100 cc. of water. This process depends on the fact that sulphur, which is present as the sulphides of iron and manganese, produces hydrogen sulphide with hydrochloric acid. The method used for the microscopic determinations of sulphur segregations is as follows: A piece of fine silk is moistened with the above solution and placed on the polished surface of the sample. The hydrogen sulphide produced precipitates black mercuric sulphide in the silk. The gas also causes small bubbles to rise under the silk which should be pressed down with a camel's hair brush. The brush is used to supply a fresh solution to the sample at the same time.

If the sulphur is uniformly distributed, the silk will be a uniform gray. If the sulphide be segregated, black streaks will be produced. Phosphorus, if present produces a lemon yellow precipitate of mercuric phosphide. There is no danger of mistaking the phosphor deposit for one of sulphur.

The reagent is allowed to act for 4 or 5 min. when the cloth is carefully removed and washed in water to remove the acid.

A simple mercuric chloride solution without the acid will corrode the FeS but not the MnS.

Hydrofluoric Acid

This reagent in the following proportions will darken any sulphides or silicates which are present:

Hydrofluoric acid (HF)	2 cc.
Absolute alcohol	98 cc.
Etch for three seconds.	

B. Reagents for Tungsten, Molybdenum, Tantalum and Their Alloys

The most commonly used method consists in treating the sample with a boiling solution of hydrogen peroxide (3 per cent solution) for 15 to 30 sec.

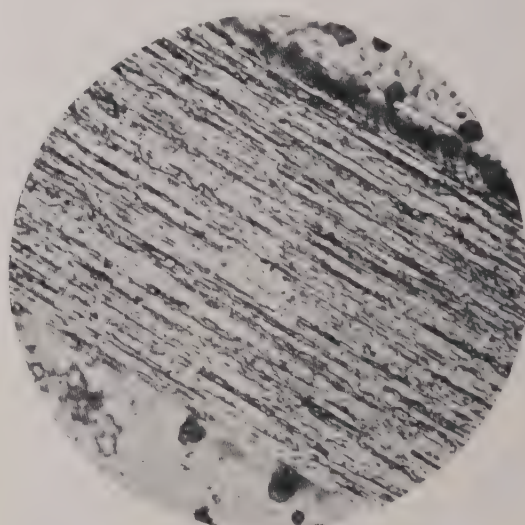


Fig. 11a. Showing How Mechanical Working Has Drawn the Grains of Tungsten Out Into Long Fibres, 1200 Magnifications

Hydrofluoric acid and nitric acid solution is used in the following proportions to develop the microstructure of tungsten ingots:

Hydrofluoric acid	3 parts
Nitric acid	1 part
Water	4 parts

Cracks and imperfections are well developed by this reagent. The solution is used hot. By varying the time of etching it is possible to obtain an etch of any desired quality.

Electrolytic etching is also employed and gives very satisfactory results. The solution used is made as follows:

Normal solution NaOH	25 cc.
Hydrogen peroxide	20 cc.

The initial current is 1.3 amp. which is quickly and progressively lowered to 0.7 amp. where it is maintained for a few seconds.

Too long an etch with the higher current density will produce a coarse pitting of the surface while too prolonged an etch with the lower density will produce fine pitting.

Tantalum may be etched successfully using a solution of HF in water (90 per cent solution) which is kept in a platinum dish. The cold acid will develop the structure. After etching, the sample should be thoroughly washed with hot water.

Gold, Platinum and Their Alloys

Due to the resistance which these metals offer to chemical attack it is necessary to etch them with aqua regia for approximately one hour.

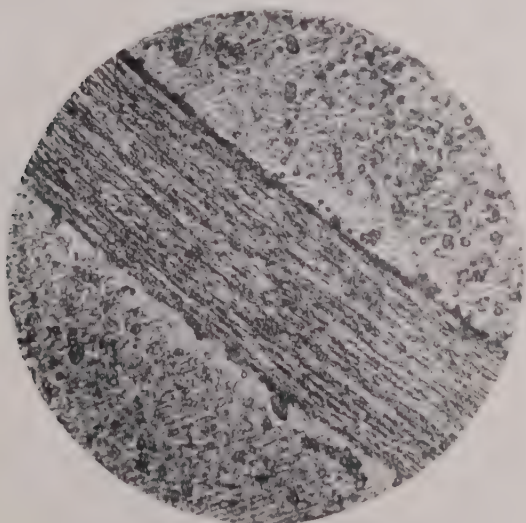


Fig. 11b. Same as Fig. 5a, 600 Magnifications

The solution is of the following composition:

Nitric acid	1 part
Hydrochloric acid	5 parts
Water	6 parts

Lead, Tin, Antimony, Bismuth, and the Bearing Metals

To etch these metals and alloys a 5 per cent solution of silver nitrate in water is very useful. Both concentrated and dilute hydrochloric is used to etch tin. The iron-tin compound is not perceptibly attacked by even concentrated hydrochloric acid.

Concentrated and dilute acetic acid is also useful for etching lead. The sample should be washed and dried quickly with water and then absolute alcohol as the surface tarnishes very rapidly.

A 5 to 10 per cent solution of nitric acid is also used to etch lead.

Copper and Its Alloys

Basic Copper Ammonium Chloride. This reagent is made by adding concentrated ammonium hydroxide to the standard solution (Heyn's reagent) until the precipitate which forms just goes into solution, giving a clear blue color.

This solution is used for etching copper and the brasses. Hoyt finds that Miller's reagent is preferable to the basic copper ammonium chloride for developing the structure of $\beta + \gamma$ brasses and probably so for the $\alpha + \beta$ group.

Miller's Reagent. Chromic acid and hydrogen peroxide. This reagent is prepared by adding a few drops of hydrogen peroxide to a dilute chromic acid solution. The specimen is immersed and kept moving in the solution for a few seconds. It is then removed and quickly washed in running water. The addition of hydrogen peroxide will turn the chromic acid solution dark brown. If the solution is too strong, large gas bubbles will be produced which will prevent uniform etching.

This reagent is equally satisfactory for all brasses and bronzes. Hoyt makes the following remarks concerning the action of this reagent on the various constituents found in the following alloys:

"In the copper tin alloys the α does not stain, while the δ remains a light blue; in the copper zinc alloys the α is unchanged while the β remains light yellow, as with ammonium persulphate."

Miller's reagent will develop the twin crystals of rolled brass very clearly. Silver may also be etched with Miller's reagent.

A 10 per cent solution of ammonium persulphate etches copper and the brasses very well. There is not the danger of pitting the surface that there is with nitric acid. The surface should be completely free from grease in order to secure a uniform etch.

Ferric Chloride. This reagent was introduced by Heycock and Neville for etching copper-tin alloys. It is also used for etching other copper alloys. A solution of the following composition is recommended by Hanne-mann.

FeCl_3	4 grams
HCl	30 cc. (1.12)
Water	1250 cc.

Both basic copper ammonium chloride and ferric chloride are used to etch copper and copper alloys. Hoyt has used both reagents for copper-tin-zinc alloys. He finds that basic copper ammonium chloride is better for the zinc rich alloys, and ferric chloride for the

tin rich alloys. Rosenhain suggests a stronger solution for copper alloys, i.e., FeCl_3 10 grams, HCl 30 cc., water 120 cc.

Ammonia. A dilute ammonia solution to which several cubic centimeters of hydrogen peroxide has been added is also used for etching copper and its alloys.

Nitric Acid. A 30 per cent solution of nitric acid is also used to etch copper. The action of the acid is rather drastic and will pit the surface badly. The author has used nitric acid to develop the microstructure of copper wire bars. The oxide appears as black inclusions. If the metal is porous, nitric acid will show this very well. Any dendritic structure present will also be developed. Dilute nitric acid is also used to etch type metals and bearing alloys.

A mixture of nitric acid and glacial acetic is also useful for developing the microstructure of copper. The following composition works well:

HNO_3 (conc.)	25 cc.
Water	25 cc.
Glacial Acetic acid	15 cc.

The following solution has been suggested for brasses containing up to 67 per cent Cu.:

Water	100 cc.
Hydrochloric acid	6 cc.
Ferric chloride	20 grams

Brasses containing up to 90 per cent copper:

Water	100 cc.
Hydrochloric acid	50 cc.
Ferric chloride	5 grams

Nickel

Hydrochloric Acid. A concentrated solution of hydrochloric acid may be used. This will require a long time to etch the sample (approx. 1 hr.).

A reagent developed in Dr. Hoyt's laboratory, at the National Lamp Works of the General Electric Company, will etch nickel in 4 seconds. It is of the following composition:

Water	2 cc.
Glacial Acetic acid	2 cc.
Conc. Nitric acid	12 cc.

Merica and Waltenberg, of the U. S. Bureau of Standards, use the following composition to etch nickel:

Water	40 parts
Nitric acid	30 parts
Glacial Acetic acid	30 parts

Aluminum

To develop the grain structure of aluminum a solution of the following composition is used:

HF	1 part conc.
Water	15 parts

After etching, the sample should be dipped in strong nitric acid, then washed and dried.

Sodium and potassium hydroxide are used in strengths varying from 20 to 50 per cent. After etching, the sample should be immersed in concentrated nitric acid to remove the black deposit formed. It should then be rinsed under running water and dried. At the Bureau of Standards a 0.1 per cent solution of sodium hydroxide in 50 per cent alcohol is used to etch aluminum for impurities.

The 20 per cent solution of sodium hydroxide will, according to Hanson and Archbutt, attack the FeAl_3 in aluminum alloys slowly and make it distinguishable by producing dark boundary lines between it and the aluminum. The action is slow, but if it be exposed to etchant too long the FeAl_3 will be dissolved out.

To determine CuAl_2 in aluminum alloys the sample is etched with a 20 per cent solution of HNO_3 at a temperature of 70 deg. C. for a few seconds and plunged in cold water. It is necessary that the process be carried on in cold water. It is also necessary that the process be carried out exactly as given, or no satisfactory results will be had. The CuAl_2 will be colored dark brown. Silicon compounds are attacked only with difficulty.

Zinc

For etching zinc dilute hydrochloric acid or Timofeev's reagent may be used. The latter solution is made up as follows:

Cr_2O_3	6 grams
HNO_3	60 cc.

add a few drops of this to 50 cc. of water to etch the zinc.

This list of reagents is far from being complete, but it includes the most common methods of etching employed at the present time. The selection of the best reagent will depend upon the physical condition and chemical composition of the metal or alloy under consideration.

The time of etching is also determined by the material to be treated. Heat treated alloys usually require a longer etching period. If the metal has been cold worked this will also alter the etching time. It is better to etch lightly and repeat the etching several times than to over etch once.

(To be continued)



LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Brushes, Electric

Relation Between Abrasiveness and Hardness of Carbon Brushes. W. C. Kalb.
Power, Aug. 25, 1925; v. 62, pp. 293-294.

Carrier-Current Communication

Carrier Current Telephony on Power Transmission Lines. N. H. Slaughter.
W. Soc. Engrs. Jour., Aug., 1925; v. 30, pp. 345-352.

Electric Drive—Ice Manufacture

Unbiased Comparison of Ice-Plant Drives.
Elec. Wld., Aug. 8, 1925; v. 86, pp. 264-266.

Electric Heating, Industrial

Electric Annealing of Steel. Harold Fulwider.
Iron Age, Aug. 6, 1925; v. 116, pp. 342-344.
(From an N.E.L.A. report.)

Electrical Machinery—Altitude Effects

Effect of Altitude on Power-Equipment Performance.
Power, July 28, 1925; v. 62, pp. 139-140.

Elevators, Electric

Changing Electric Power Source for Elevator Equipment. J. A. Jackson.
Power, Aug. 25, 1925; v. 62, pp. 281-283.
(Discusses six courses available when it becomes necessary to revise d-c. elevator equipment for use with a-c.)

Furnaces, Industrial

Efficiency of Heating Furnaces. E. H. Koenig.
Iron Tr., July 30, 1925; v. 77, pp. 249-253.
(Comparison of performance of continuous and intermittent types. Presents tables of data.)

Grounding

Grounding the Neutral. Edgar D. Sibley.
Iron & St. Engr., Aug., 1925; v. 2, pp. 331-334.
(Experiences of the Metropolitan Edison Co.)

High Pressure

Certain Aspects of High-Pressure Research. P. W. Bridgman.
Franklin Inst. Jour., Aug., 1925; v. 200, pp. 147-160.

Insulators—Testing

Locating Defective Insulators. George A. Iler.
Elec. Wld., Aug. 8, 1925; v. 86, pp. 257-260.
(Describes a new type of live-line testing stick which gives a direct reading.)

Laboratories

Utility Uses Testing Laboratory. W. R. Framp-ton.
Elec. Wld., Aug. 15, 1925; v. 86, pp. 305-308.
(Illustrated description of the apparatus test department of the Alhambra shops of the Southern California Edison Co.)

Machinery—Erection

Electric Power Club Instructions for Installing Oil Circuit Breakers.
Ind. Engr., Aug., 1925; v. 83, pp. 373-379, 402.
(Also includes similar instructions covering power switching equipment.)

Oscillators, Vacuum Tube

Generation of Polyphase Oscillations by Means of Electron Tubes. René Mesny.
Inst. Radio Engrs. Proc., Aug., 1925; v. 13, pp. 471-476.

Radio Transmitters

Recent Commercial Development in Short Wave Transmitters and Receivers. S. E. Anderson and others.
Inst. Radio Engrs. Proc., Aug., 1925; v. 13, pp. 413-436.

Short Circuits

Short-Circuit Calculating Board. E. R. Stauffacher.
Elec. Wld., Aug. 1, 1925; v. 86, pp. 223-224.
(Short description of equipment used by the Southern California Edison Co.)

Water Turbines

High Specific Speed Hydraulic Turbines in Their Bearing on the Proportioning of the Number of Units in Low-Head Hydro-Electric Plants.
A.S.C.E. Proc., Aug., 1925; v. 51, pp. 999-1064.
(A symposium of six papers, by different authors, covering various phases of the subject.)

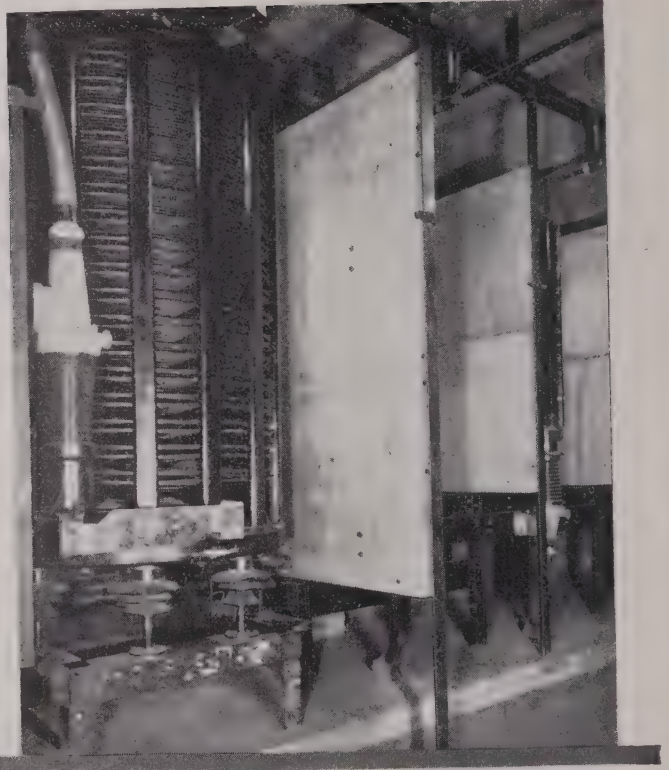
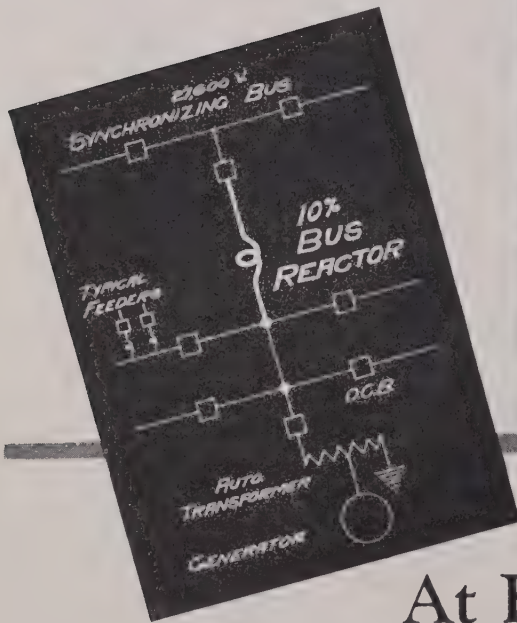
NEW BOOKS

Course of Metallurgy for Engineers. F. C. Thompson. 240 pp., 1925, Lond., Witherby & Co.

Effective Regulation of Public Utilities. John Bauer. 381 pp., 1925, N. Y., Macmillan Co.

Heat Engines; Steam, Gas, Steam Turbines and Their Auxiliaries. Ed. 3. John R. Allen and Joseph A. Bursley. 422 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

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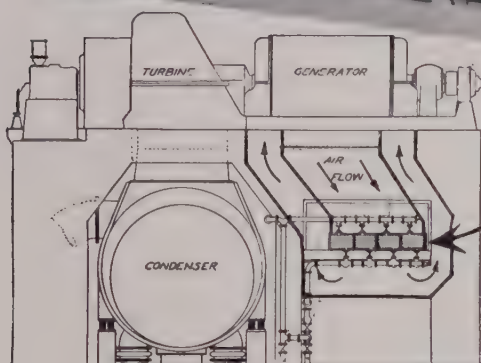
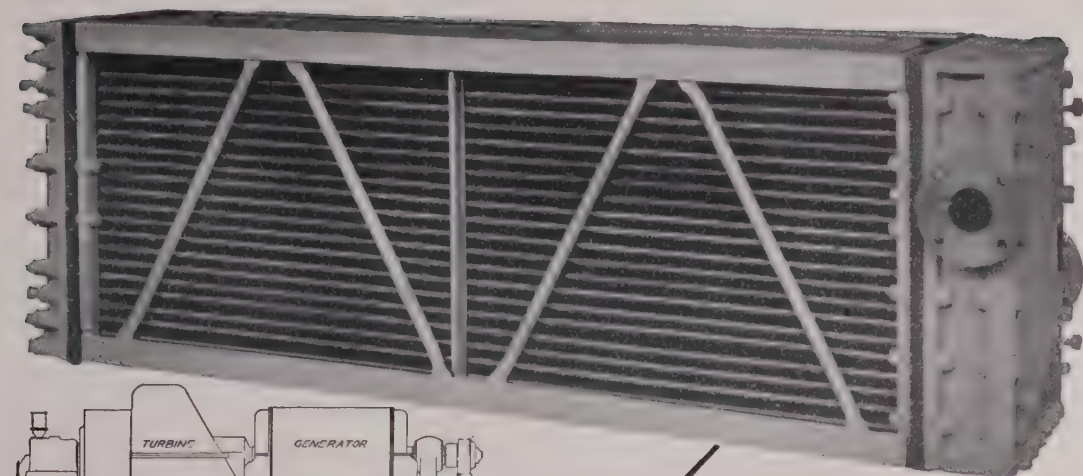
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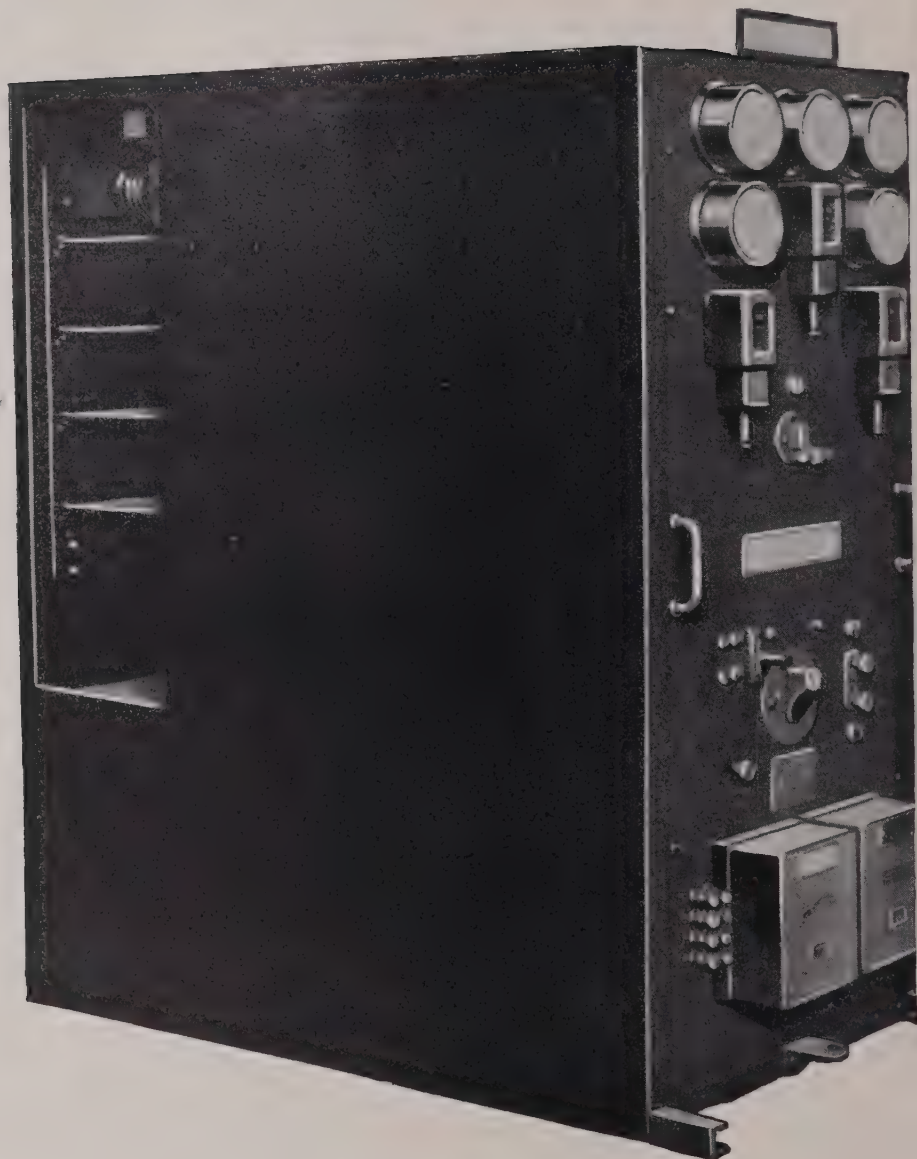
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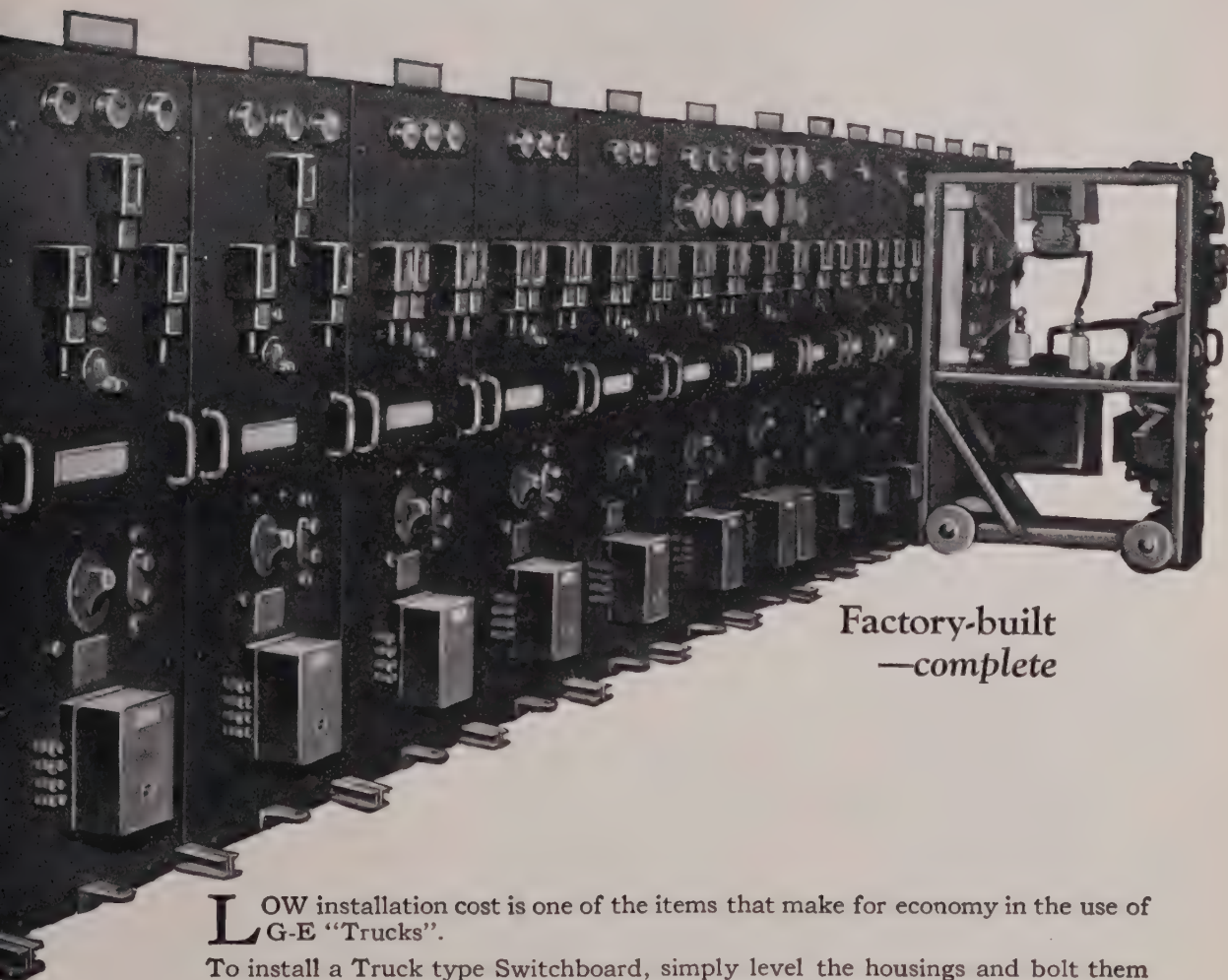
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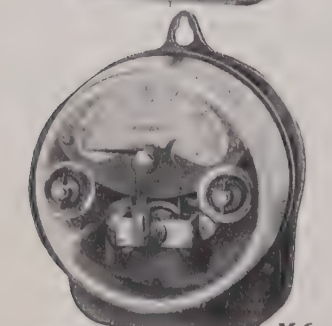
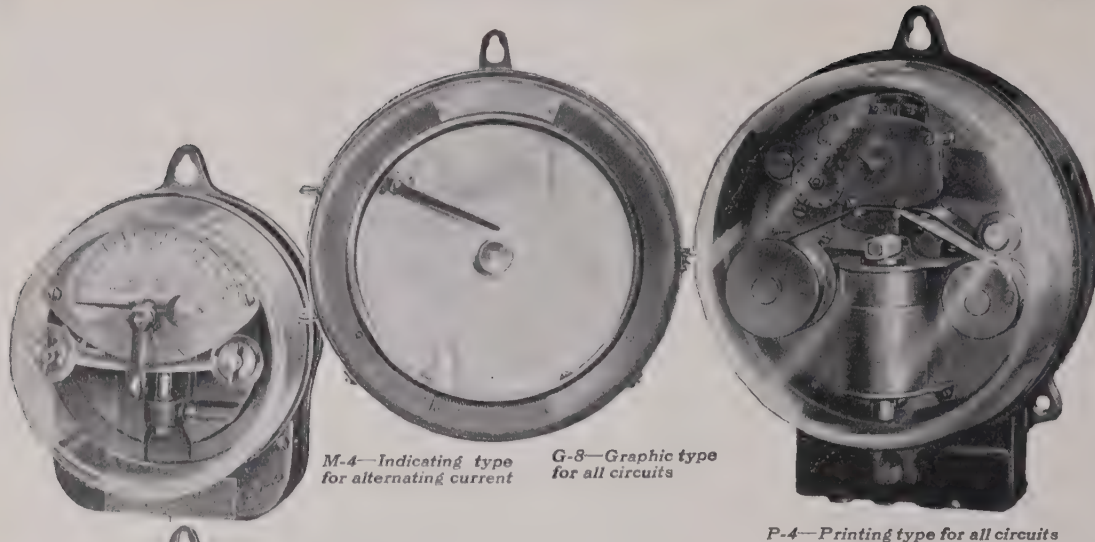
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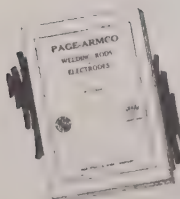
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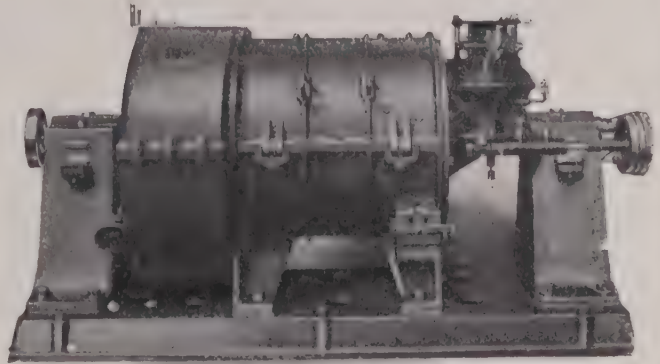
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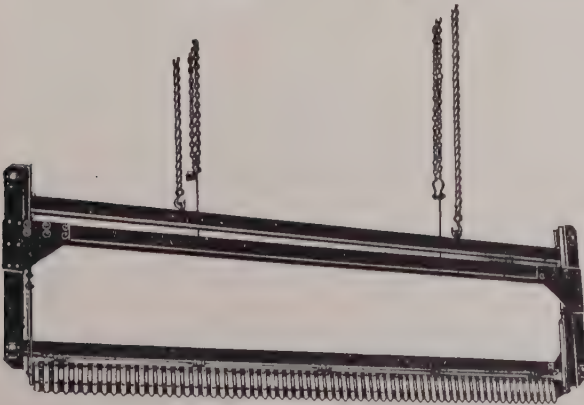
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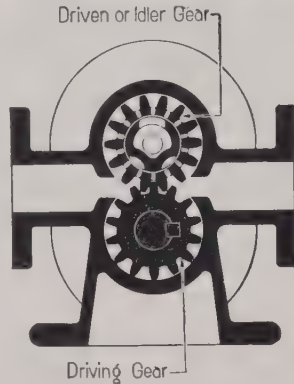
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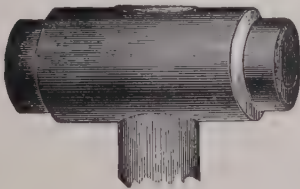
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When you buy die-castings from us, you are assured of the same high quality that has established our Dutch Boy trademark as a mark of excellence on babbitts, solder and paint materials.



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Die-Casting Division

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Western Representatives: E. R. McCormick, 2599 Cadillac Ave., Detroit, Mich. A. H. Bergedick, 667 Bowen Street, Dayton, Ohio. A. A. Gildemeister, 444 Fourth Street, Toledo, Ohio.

This is one of a series of advertisements describing some of the interesting and unusual uses of die-castings in various fields.

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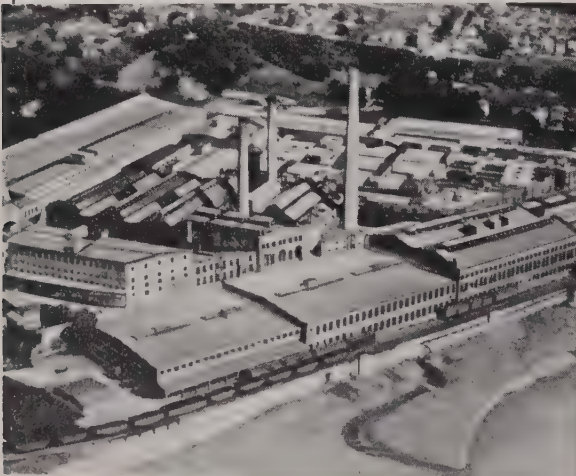
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William J. Lickert, Combustion Engineer, Champion Coated Paper Co., Hamilton, O., says:

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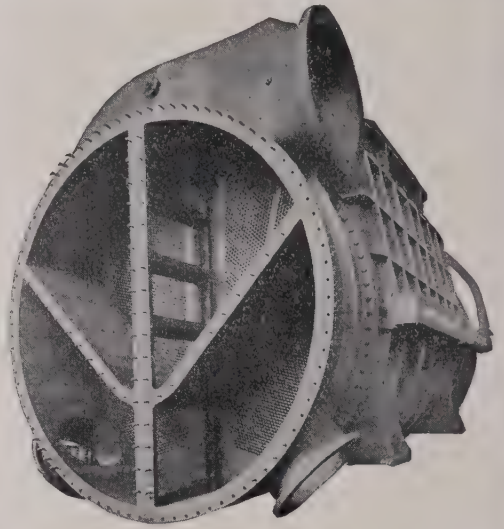
"When we have plenty of exhaust steam we operate the motor-driven fan; the turbine-driven fan is used when we don't have enough steam for our feed water heater. When our boilers are crowded we often use both fans.

"Our Buffalo Forge fans have given us such satisfaction that we're going to have 5 of them in our new boiler room—3 motor-driven, 2 turbine-operated."

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A C. H. Wheeler Surface Condenser which embodies the Dual Bank Design, which deflects the hot condensate from the upper pass to the hotwell without refrigeration by the low tubes. This results in a gain of several degrees in the hotwell temperature and a corresponding saving in the fuel. This arrangement also decreases the pneumatic resistance between the exhaust and the air pump suction outlets.

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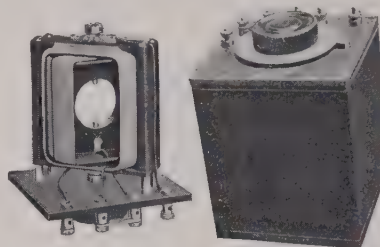
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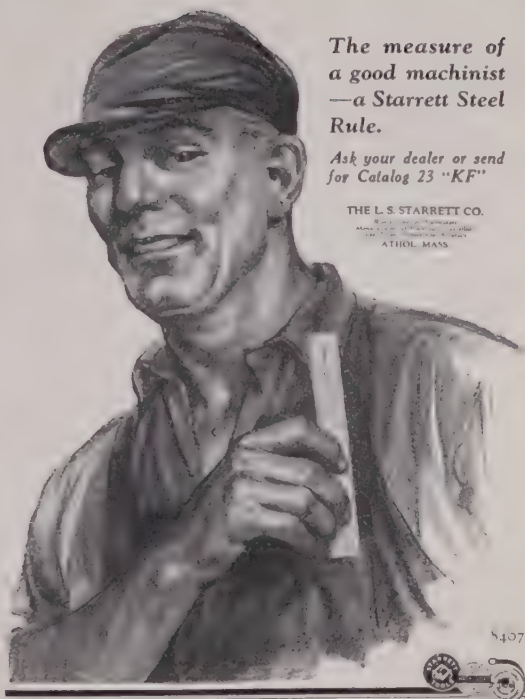
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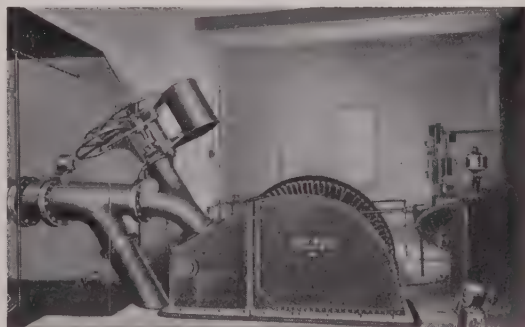
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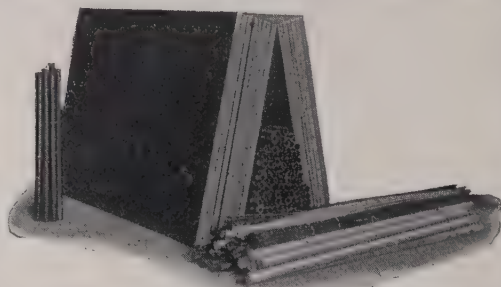
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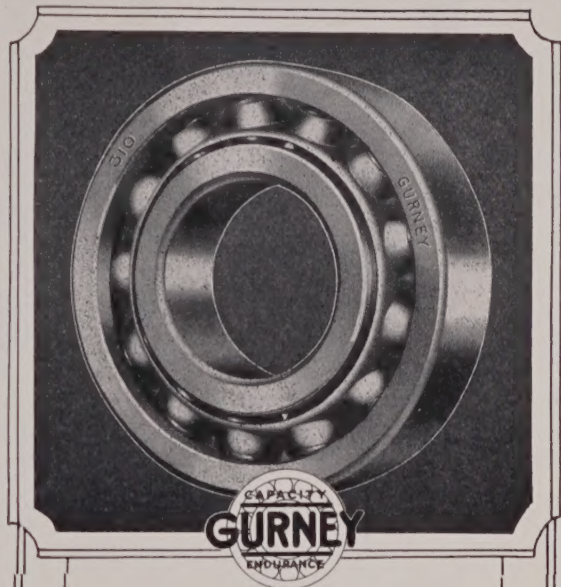
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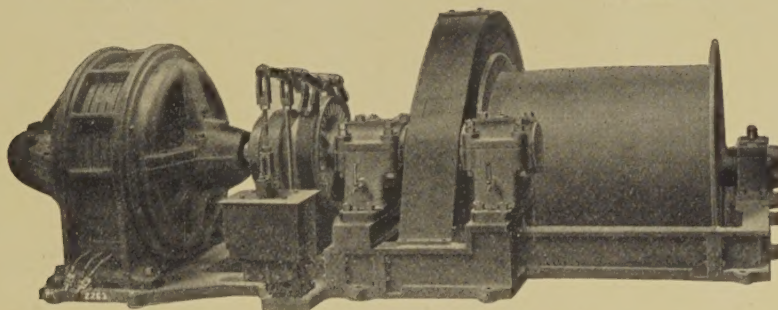
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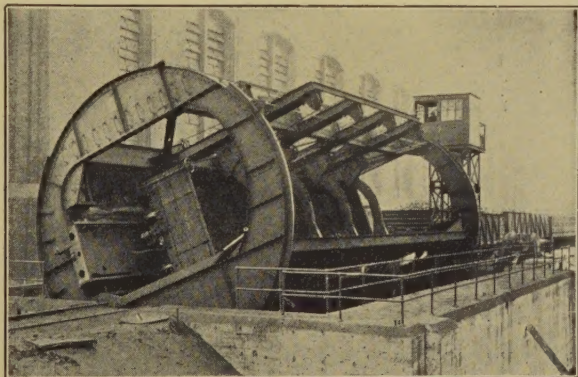
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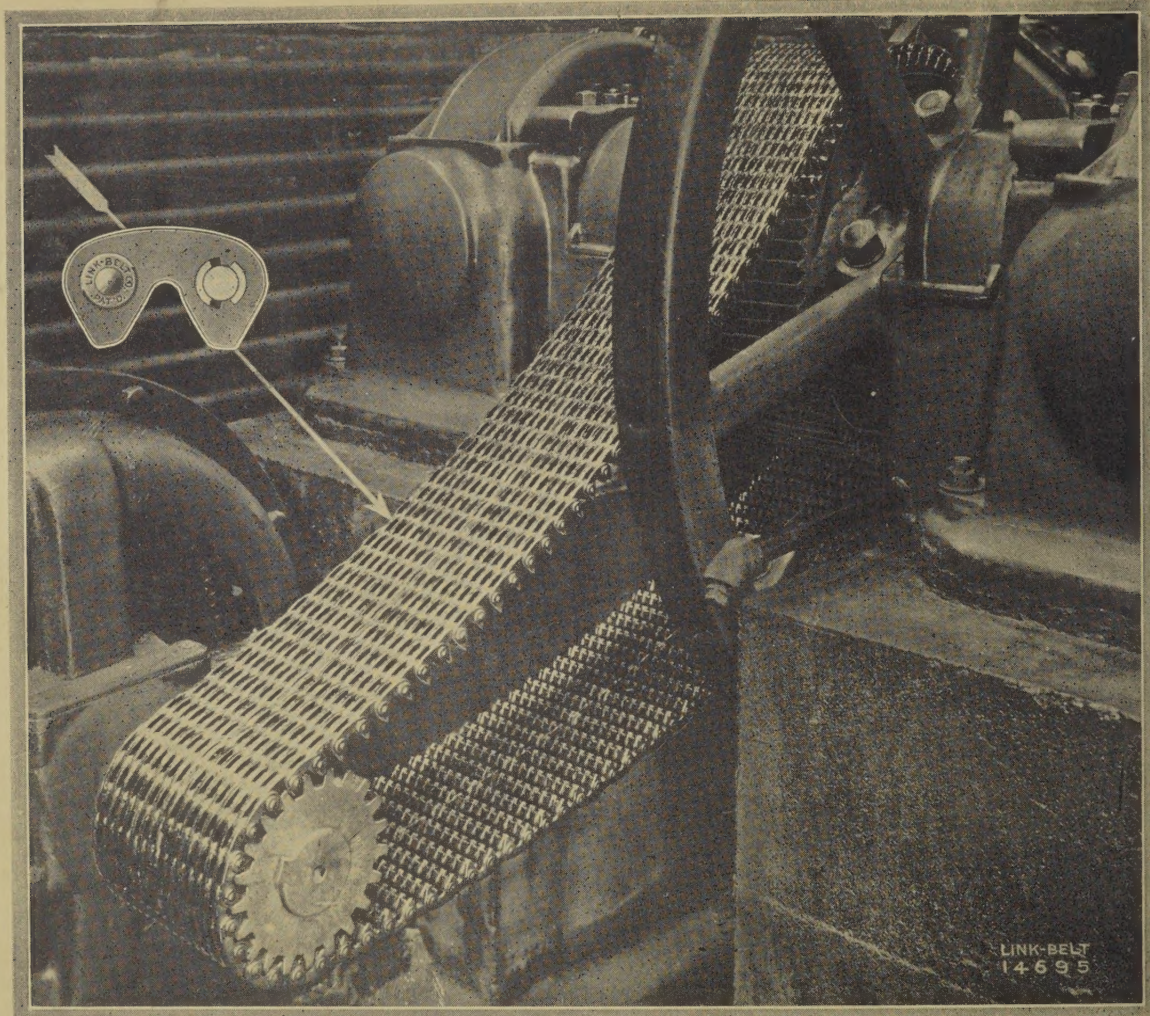
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